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CHEMICAL COMPOSITION OF CERTAIN FORAGE CROPS AS AFFECTED BY FERTILIZERS AND SOIL TYPES[1]

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INTRODUCTION

The quality of forage crops as livestock feeds depends upon many factors, including the kind of forage, its stage of maturity, its palatability, and its chemical composition. Although it has long been recognized that forage crops produced on certain soils make better quality livestock feed than the same crops produced on other soils under different or similar climatic conditions, the knowledge that certain factors of feeding quality are dependent upon the content of mineral constituents as well as upon the protein and other organic constituents of the crops is of relatively recent origin. The comprehensive review of Vandecaveye (*4*)[3] and Beeson (*2*) pertaining to investigations of the chemical composition of crops reveals that the composition of forage crops and, therefore, their feeding quality are affected by applications of fertilizers and by differences in soil properties as manifested by soil types.

In 1932 the authors (*5*) reported the results of 265 field-plot experiments designed to study the effect of different fertilizer treatments on the yield of crops produced on the major agricultural soil types of the State of Washington. Samples of many of the forage crops in these and subsequent experiments were saved for chemical analyses. The chief object of the present paper is to present the analytical results, and also a general interpretation of the effects of fertilizer treatments and soil types on the nitrogen, phosphorus, potassium, and calcium content of mixed pasture grasses, mixed hay, alfalfa hay, and oats and wheat cut for hay at the milk stage of maturity.

EXPERIMENTAL PLAN

FERTILIZER TREATMENTS

The samples of crop material used for chemical analysis were obtained from two series of fertilizer experiments carried on over a period of years on different soil types located largely in western Washington. The fertilizer treatments used in the two series of experiments are shown in table 1. The first series was designed for studies of pasture grass exclusively, and samples of herbage were obtained from eight of the plots. The part of each plot from which the samples of herbage were

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[3] Italic numbers in parentheses refer to Literature Cited, p. 220.

taken was enclosed by a fence and the remaining part was accessible for pasturing. The fertilizer treatments for the other series served for the study of forage crops other than pasture herbage.

The fertilizers were broadcast in the spring in all cases. For wheat, oats, and new seedings of alfalfa the fertilizer material was mixed with the soil by disking or harrowing before the crops were planted. If more than one annual application of fertilizer was made before crop samples were taken for chemical analysis, this is indicated in the table giving the analytical results. All the experiments were designated by a number preceded by a capital letter in accordance with the system used previously (*5*). The letter preceding each number indicates the year during which the experiment was in progress and the crops were sampled. Thus, B represents the year 1929; C, 1930; D, 1931; E, 1932; and F, 1933. The following symbols are used: N, nitrogen (N); P, phosphoric acid (P_2O_5); K, potash (K_2O); and Ca, lime hydrate or carbonate.

TABLE 1.—*Fertilizer treatments in the 2 series of experimental plots from which crop materials used for chemical analysis were obtained*

EXPERIMENTAL SERIES 1

Plot [1]	Fertilizer material	Quantity applied per acre
		Pounds
Check	None	None
P	16 percent superphosphate	600
PK	16 percent superphosphate	600
	50 percent muriate of potash	200
PKCa	16 percent superphosphate	600
	50 percent muriate of potash	200
	Hydrated lime	1,000
NPKCa	20 percent sulfate of ammonia	250
	16 percent superphosphate	600
	50 percent muriate of potash	200
	Hydrated lime	1,000

EXPERIMENTAL SERIES 2

Check	None	None
N	16 percent nitrate of soda	300
NP	16 percent nitrate of soda	300
	16 percent superphosphate	600
PK	16 percent superphosphate	600
	50 percent sulfate of potash	200
NPK	16 percent nitrate of soda	300
	16 percent superphosphate	600
	50 percent sulfate of potash	200
NPKCa	16 percent nitrate of soda	300
	16 percent superphosphate	600
	50 percent sulfate of potash	200
	Crushed limestone	2,000

[1] The symbols used for plot designations and in other parts of this paper have the following meanings: N=Nitrogen (N); P=phosphoric acid (P_2O_5); K=potash (K_2O); and Ca=lime hydrate or carbonate.

METHODS OF SAMPLING AND CHEMICAL ANALYSES

Crop samples were obtained from 45 experiments on 19 identified and certain unidentified soil series representing a total of 29 soil types. Each experiment consisted of 5 or 6 differently treated plots; consequently, 401 crop samples were obtained to determine their ash, nitrogen, phosphorus, potassium, and calcium content.

Pasture grass and mixed hay.—The yields, and also the samples of pasture herbage and mixed grass hay reserved for chemical analysis, were obtained from the fence-enclosed part of each of the experimental areas. The herbage in the pastures was composed of mixed grasses

and clover consisting largely of white clover and occasionally some red or alsike clover, the density of the clover depending upon the soil type and the fertilizers applied. The yields of pasture herbage and mixed hay were obtained by cutting two separate square-yard quadrates with a hand sickle. The remaining part of the enclosed area was then cut and the grass removed, except in a small section where the crop was allowed to grow to the hay stage of maturity. The stage of growth, which was the pasturing stage (before definite jointing of the grass occurred), rather than specific time intervals was selected for the pasture cuttings. After the green weight of the herbage on the quadrates was obtained, a representative sample was selected for chemical analysis. Care was observed to eliminate soil and other foreign materials from the samples, but no special effort was made to free the samples from dust or other mineral matter adhering to the herbage, or to segregate the different botanical species. The pasture samples were dried in an oven at 70° C.

As nearly as it is possible to determine in a stand of mixed grasses and clover, the blooming stage was selected for cutting the mixed grass hay. A representative sample of the hay, freed from soil and other foreign material, was selected for chemical analysis and dried in an oven at 70° C.

Alfalfa.—Two or three separate square-yard quadrates (the number depending upon uniformity of stand in the plot) were cut in each plot to determine yields and to obtain samples for analysis. The half-bloom stage of maturity was selected for cutting the crop. All samples saved for chemical analysis were carefully examined for stage of maturity, and those not strictly complying were rejected. Plants other than alfalfa were sorted out and discarded, but no attempt was made to determine alfalfa varieties. The hay samples were air-dried or dried in an oven at 70° C., whichever was more convenient.

Oats and Wheat Hay.—Samples for chemical analysis were obtained from two or three separate square-yard quadrates and cut at the milk stage of maturity. The samples of crop material selected for analysis were freed from weeds and plants other than oats or wheat and air-dried.

Chemical Analyses.—All the plant samples were ground in a Wiley mill and suitable portions were dried at 105° C. for 3 hours to determine the dry weight. The nitrogen, ash, phosphorus, and calcium content was determined by the official methods (1, *pp. 121–137*) for these constituents. The potassium content was determined by the cobaltinitrite method of Volk and Truog (*7*). All analytical results were calculated on the basis of dry weight of the plant materials.

EXPERIMENTAL RESULTS

Although the yields of the various crops used in the fertilizer experiments are recorded in the tables which follow, they will not be discussed in detail since this has been done elsewhere (*5*, *6*). The fertilizers used for each of the two series of experiments were uniform in composition and applied in equal amounts. Their effect on like crops, therefore, should be relatively uniform, except for the influence of climatic factors and soil properties. Since certain soil properties of different soil types in the same soil series as well as soil properties

of different soil series may vary decidedly, and since the number of experiments established on any one soil series is small, some broad arbitrary grouping of soils and also of climatic conditions becomes necessary.

Both climatic factors and the parent material from which the soil is derived have a profound influence on inherent soil properties developed during the process of soil formation. A logical broad division of climatic conditions is the humid climate of western Washington and the relatively arid climate of central Washington. This grouping was applied to the experiments with alfalfa, the only crop grown on a substantial number of irrigated soils in central Washington and nonirrigated soils in the humid area of western Washington. The logical broad division of parent material from which the soils in western Washington are derived is to place the mineral soils in the glaciated area of northwestern Washington in one group, called for convenience soils derived from glacial material, and those in the nonglaciated area of southwestern Washington in a second group, called for convenience soils derived from residual material. Some of the soils derived from alluvial material in both northwestern and southwestern Washington, however, may contain both glacial and residual material. A third group consists of soils derived from organic material. This grouping of soils was applied to the pasture grass and mixed hay experiments. No special grouping of soils or climate was made for the oat and wheat experiments.

COMPOSITION OF PASTURE GRASS, FIRST CUTTING

In all cases the pasture herbage consisted of mixed grasses and clover, largely white clover, the density of the clover depending upon soil type and fertilizer treatments. The analytical results and also the yields of 13 experiments on western Washington mineral soils are recorded in table 2. The data show wide differences in the composition as well as in the yields of herbage from plots treated with different fertilizers on the same soil type, and also of herbage produced on different soil types. The extreme values for ash ranged from 5.09 to 21.97 percent, for nitrogen from 1.33 to 3.92 percent, for phosphorus from 0.203 to 0.554 percent, for potassium from 0.63 to 4.40 percent, and for calcium from 0.27 to 1.59 percent.

In certain cases, like fertilizer treatments on different soils produced unlike effects which may have been accentuated by variations in meteorological conditions during different years. No attempt was made, however, to evaluate the influence of meteorological factors. The effect of these factors over a period of 3 or 4 years, the extent of the period of investigation, should have a tendency to be compensating rather than cumulative.

It is evident from the data in table 2 that the nitrogen and mineral content of the herbage produced on certain soils was consistently larger with and without fertilizers than that of herbage produced on certain other soils. This is noticeable also in the data for other forage crops shown in the tables which follow. Soil characteristics appear to have a pronounced influence on the composition of crops.

TABLE 2.—*Yield and composition of pasture grass (first cutting) as affected by different fertilizers and different soil types*

SOILS DERIVED FROM GLACIAL MATERIAL

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C-305	Puget silty clay	1	Check	1.39	7.96	1.99	0.316	0.99	0.59
			P	1.37	7.99	2.27	.375	.63	.68
			PK	1.35	9.18	2.29	.395	1.52	.61
			PKCa	1.27	9.37	2.36	.398	1.84	.70
			NPKCa	1.64	9.21	2.21	.358	2.21	.67
C-306	do	1	Check	1.58	7.31	2.05	.318	2.75	.33
			P	1.61	6.93	2.00	.328	3.15	.34
			PK	1.97	8.53	1.80	.329	3.48	.35
			PKCa	1.81	8.10	1.90	.352	3.90	.35
			NPKCa	2.07	8.19	2.30	.334	4.21	.37
E-37	Bellingham silt loam.	1	Check	.87	6.71	1.39	.267	1.66	.29
			N	1.23	7.59	2.21	.316	2.65	.40
			NP	1.19	8.71	2.43	.359	2.04	.29
			PK	.97	7.33	1.33	.278	1.32	.28
			NPK	1.22	9.24	2.41	.435	3.15	.27
			NPKCa	1.15	8.63	2.44	.387	2.81	.47
E-29	Custer silt loam	1	N	1.00	11.19	2.24	.204	.71	.40
C-301	Bellingham silt loam.	1	Check	.84	8.86	2.48	.408	1.06	.66
			P	.85	9.83	2.42	.371	3.70	.50
			PK	1.22	9.61	2.24	.387	1.97	.50
			PKCa	1.33	9.89	2.52	.428	2.17	.82
			NPKCa	1.23	9.76	2.21	.403	2.09	.63

SOILS DERIVED FROM RESIDUAL MATERIAL

E-107	Chehalis loam	1	Check	0.63	21.17	2.30	0.282	2.04	0.43
			N	.55	19.25	2.10	.256	2.21	.54
			NP	.71	21.02	2.04	.290	1.89	.50
			PK	.61	18.20	2.41	.257	2.06	.59
			NPK	.62	21.97	2.53	.254	2.02	.73
			NPKCa	.92	17.32	2.58	.303	2.60	.73
E-55	Sacramento silty clay loam.	1	Check	.75	11.53	3.03	.312	1.83	1.45
			N	1.13	8.37	2.20	.280	1.45	.82
			NP	1.49	8.55	1.97	.361	1.23	.79
			PK	1.03	12.04	3.36	.357	3.10	1.59
			NPK	1.51	9.00	2.47	.411	2.74	.83
			NPKCa	1.71	11.69	1.99	.368	3.00	.80
D-118	Chehalis silty clay loam.	1	Check	.60	10.56	2.43	.433	3.23	.55
			N	.90	12.36	2.78	.521	3.35	.59
			NP	.60	12.84	3.04	.554	3.61	.74
			PK	.57	13.16	2.48	.484	2.81	.75
			NPK	.91	11.52	2.87	.532	3.68	.53
			NPKCa	.82	12.03	2.94	.491	3.34	.65
C-302	do	1	Check	.79	10.98	2.20	.354	2.75	.64
			P	.72	10.89	2.57	.448	3.52	.64
			PK	.69	13.92	2.26	.397	3.00	.82
			PKCa	.88	13.37	2.48	.428	3.14	.81
			NPKCa	1.39	11.20	2.09	.406	3.81	.83
E-13	Salkum clay loam	1	Check	.38	11.49	2.03	.299	2.24	.71
			N	.72	7.55	2.83	.377	2.92	.80
			NP	1.00	8.86	3.55	.459	3.60	.66
			PK	.52	8.13	2.10	.347	2.22	.64
			NPK	1.23	9.51	3.34	.441	4.08	.61
			NPKCa	1.20	9.15	2.77	.384	3.05	.70
E-105	Olympic silty clay loam.	1	Check	.06	8.25	1.75	.203	1.47	.55
			N	1.16	8.89	3.56	.307	2.56	.47
			NP	.73	9.20	3.37	.393	2.82	.44
			PK	1.03	11.70	3.92	.508	4.40	1.14
			NPK	.97	9.15	3.44	.421	3.72	.53
			NPKCa	.61	11.23	3.55	.389	3.82	1.27
D-50	do	1	Check	93	9.29	2.90	.340	4.02	.56
			N	1.21	9.42	2.91	.342	3.95	.62
			NP	1.82	8.96	2.60	.341	4.11	.58
			PK	.96	9.18	3.15	.303	3.93	.56
			NPK	1.85	8.63	2.51	.361	4.03	.67
F-16	Salkum clay loam	2	Check	.89	6.28	1.47	.291	2.30	.39
			N	3.29	5.40	1.93	.249	2.66	.35
			NP	3.46	5.09	1.93	.300	2.36	.32
			PK	1.02	5.94	1.47	.230	2.63	.34
			NPK	2.57	6.16	1.85	.315	2.75	.34

On the basis of weighted averages, disregarding the effect of soil types and of meteorological conditions in different years, the herbage on the fertilized plots was benefited in that it contained increased percentages of nitrogen, phosphorus, and potassium, although not of ash and calcium, except possibly where lime was applied. These

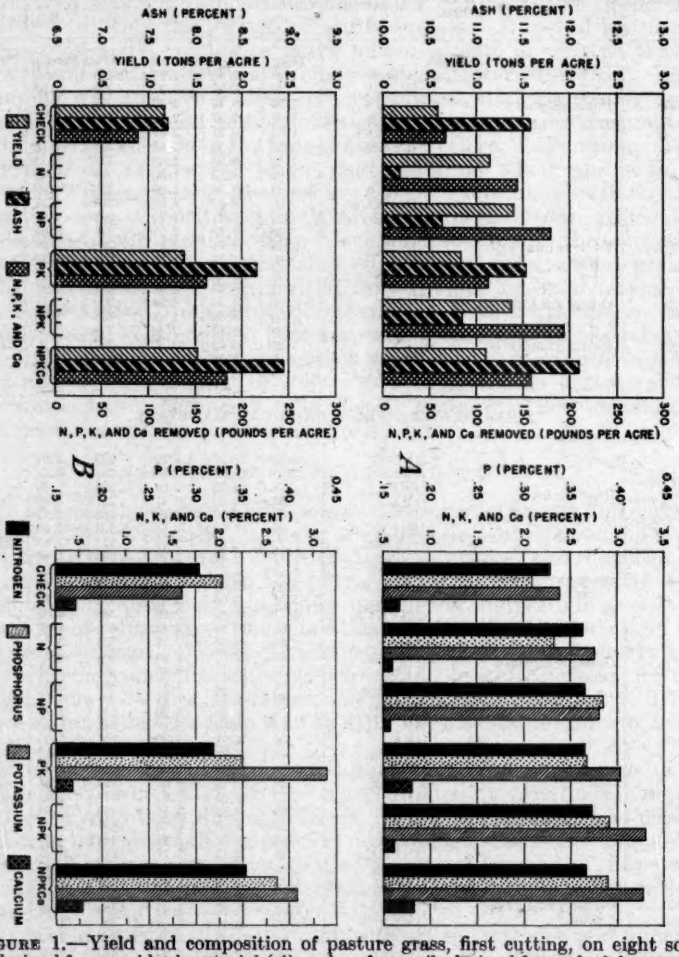

FIGURE 1.—Yield and composition of pasture grass, first cutting, on eight soils derived from residual material (*A*) and on four soils derived from glacial material (*B*).

findings are illustrated in figure 1 for eight experiments on soils derived from residual material, and four experiments on soils derived from glacial material. The tendency of nitrogen fertilizers to cause an increased percentage of nitrogen in the pasture herbage is in agreement with the results of many investigations referred to in the review by Vandecaveye (*6*). The tendency of phosphate fertilizers

to cause an increase in the phosphorus content of the herbage conforms with many of the results referred to in the above review and also with those reported by Fergus and Miller (*3*). Another interesting point indicated in figure 1 is that the herbage on the fertilized plots removed distinctly larger quantities of plant nutrients from the soil than did the herbage on the check plots. Evidently the increase in yields and in concentration of plant nutrients in the herbage resulted in a larger demand on the supply of plant nutrients in the soil.

In order to test the significance of the average values in figure 1 and subsequent figures an analysis of variance of the data appeared to be desirable, although no special experimental design for replication and randomization was planned for these experiments. The plots on soils derived from like parent material and receiving like fertilizers for like crops were considered as replicates and treated as one sample. It is conceivable that, regardless of the variability in soil types within the sample and the variability in meteorological conditions in different years, soil types derived from like parent material may possess a sufficient number of inherent characteristics in common to cause a definite trend in the effects produced by like fertilizers for like crops. An analysis of variance should be useful in ascertaining such trends, which in turn should be helpful in the interpretation of the experimental results. The summaries of the analysis of variance based on a 5-percent level of the *t* value are presented in separate tables for different crops. The summary for appropriate data pertaining to the first pasture-herbage cuttings is presented in table 3.

Nitrogen

Although the average values for nitrogen presented in table 3 for the first cutting of pasture herbage on eight soils derived from glacial material indicate substantial increases as a result of fertilizer applications, the values for the differences obtained by the analysis of variance on the 5-percent level are too small to be significant.

Table 3.—*Significance of differences in composition of pasture grass (first cutting) as indicated by analysis of variance (five-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	2.16	2.57	2.62	2.53	2.68	0.87	0.95	------	------
P	.303	.331	.382	.352	.396*	.087	------	0.123	------
K	2.35	2.74	2.71	2.81	3.27	1.04	------	------	2.45
Ca	.62	.58	.54	.74	.56	.31	------	------	------

	Means in percent of dry matter for soils indicated [1]											
	E-107	E-55	D-118	E-13	E-105	D-50	F-16	E-37				
N	2.28	2.61	2.72	2.77	3.21	2.82	1.74	1.96	.59	------	------	------
P	.268	.344	.505	.385	.366	.337	.287	.331	.059	------	------	------
K	2.04	2.07	3.38	3.01	2.99	4.01	2.54	2.16	.72	------	------	------
Ca	.56	1.10	.63	.68	.63	.60	.35	.31	.21	------	------	------
N	2.24	2.42	2.78	2.94	3.03	2.73	1.81	2.11	------	.50	------	------
P	.271	.360	.501	.387	.381	.336	.297	.335	------	------	.064	------
K	2.04	2.56	3.24	2.85	3.20	4.00	2.56	2.04	------	------	------	.82

[1] The values for different soils show significant differences among soils.
*=Significant increase.

It is evident that the effect produced by the fertilizers on different soil types varies widely. The analysis of variance of this effect indicates that a difference of 0.59 percent of nitrogen between the means for herbages of different soil types is significant. If the lowest mean value for the various soils shown in table 3 under "Difference required for significance," (first column) is used as a basis for comparison, it is found that the difference of 0.59 required for significance was exceeded in the majority of cases. Insofar as variations in nitrogen content of the first cutting of pasture herbage is concerned it appears that the effect of soil type was more pronounced in causing them than was the effect of fertilizers.

When the results of the plots receiving nitrogen-bearing fertilizers (omitting the results of the PK treatment from the statistical analysis) are compared with the results of the check plots, the values required for significance are slightly larger (table 3, under "Difference required for significance," second column), although the tendency indicated above where all the fertilizer treatments are included in the comparison is not altered appreciably. One of the reasons for the higher values required for significance when the PK treatment is omitted is that in most cases this treatment resulted in an increased proportion of clover to grasses, and consequently in a generally higher nitrogen content of the herbage.

Phosphorus

The fertilizer treatments had a greater effect on the phosphorus content than on the nitrogen content of the pasture herbage. The difference in phosphorus required for significance between any two means for fertilizer treatments is 0.087 percent (table 3, under "Difference required for significance," first column). This value was exceeded for the NPK treatments and closely approached for the NP treatments as compared with the checks. Soil characteristics as expressed by soil types, however, also caused significant differences in the phosphorus content of the herbage. The value of 0.059 required for significance between any two means for soils is exceeded in the majority of cases when the lowest mean value for soils is used as a basis for comparison.

When the analysis of variance is confined to plots receiving phosphate-bearing fertilizers in comparison with the check plots the values for differences required for significance for both fertilizer and soil types are larger (table 3, under "Difference required for significance," third column). In this case the differences due to the effect of soil types are still significant, but the value of 0.123 for only those fertilizers that contained phosphates was not approached in any case. The relatively low average phosphorus content in the herbage obtained from the PK plots suggests that in the absence of nitrogen fertilizers the herbage had a tendency to absorb a smaller amount of the phosphorus applied as phosphates to the soil.

Potassium

The average values in figure 1 show a definite increase in potassium content of the herbage produced on soils treated with fertilizers, and a further increase when potash was included in the fertilizers. The statistical data in table 3 for potassium reveal, however, that the

differences indicated by the average values are not significant. When the effect of soil type on the potassium content of the herbage is considered by the analysis of variance, it appears that this effect is significant, as in the majority of cases the difference required for significance was exceeded.

Calcium

The apparent differences in calcium content of pasture herbage, as indicated by the average values for calcium in figure 1, proved to be statistically nonsignificant insofar as they were affected by fertilizer treatments. As may be noted from the data on calcium in table 3, these differences are significant insofar as they are applied to soil types. Pasture grass produced on various soil types may be expected to contain significantly different percentages of calcium.

COMPOSITION OF PASTURE GRASS, SECOND CUTTING

The yields and analytical results for the second cutting of pasture herbage grown on five soils derived from glacial material and five soils derived from residual material are reported in table 4. The variations in composition and yields resulting from the application of different fertilizers, and from different soil types, were similar in character and magnitude to those for the first cutting. Like that of the first cutting the herbage of the second cutting contained larger percentages of nitrogen and minerals when produced on some soils than on others. The weighted averages illustrated in figure 2 show that in general the yields were considerably smaller, and consequently the total quantities of nutrients removed from the soil in the various experiments were less, as might be expected, for the second than for the first pasture cutting. The outstanding difference between the two cuttings with respect to chemical composition is that the percentages of ash, nitrogen, phosphorus, and potassium were smaller for the second cutting.

The effect of the fertilizers in general was manifested by an apparent increase in the avarage ash content of the herbage and an increased removal of total nutrients. The nitrogen fertilizers caused a larger average nitrogen content of the herbage on the soils derived from residual material, but not of the herbage on soils derived from glacial material. The phosphate and potash fertilizers produced an increased average percentage of phosphorus and potassium respectively in the herbage on both groups of soil. The average calcium content of the herbage was not affected regularly or appreciably by the various fertilizer treatments.

The significance of these apparent differences may be evaluated from table 5 in which the data suitable for the analysis of variance are summarized. Careful consideration of the influence of the fertilizers in general on the composition of the second cutting of pasture grass reveals no significant effect on the percentages of nitrogen, potassium, or calcium in the herbage. It appears, however, that the NP treatments resulted in a significant increase in the phosphorus content of the herbage, and that the PK treatments caused increases in phosphorus which approached significance.

Comparing the phosphate-bearing fertilizers and the potash-bearing fertilizers separately for their effect on the percentages of phosphorus

and potassium respectively in the herbage did not change the foregoing relationship to any significant degree. The value for the PK treatments suggests that the supply of phosphorus and potassium added to the soil by the phosphate and potash fertilizers was more effective for the second than for the first cutting.

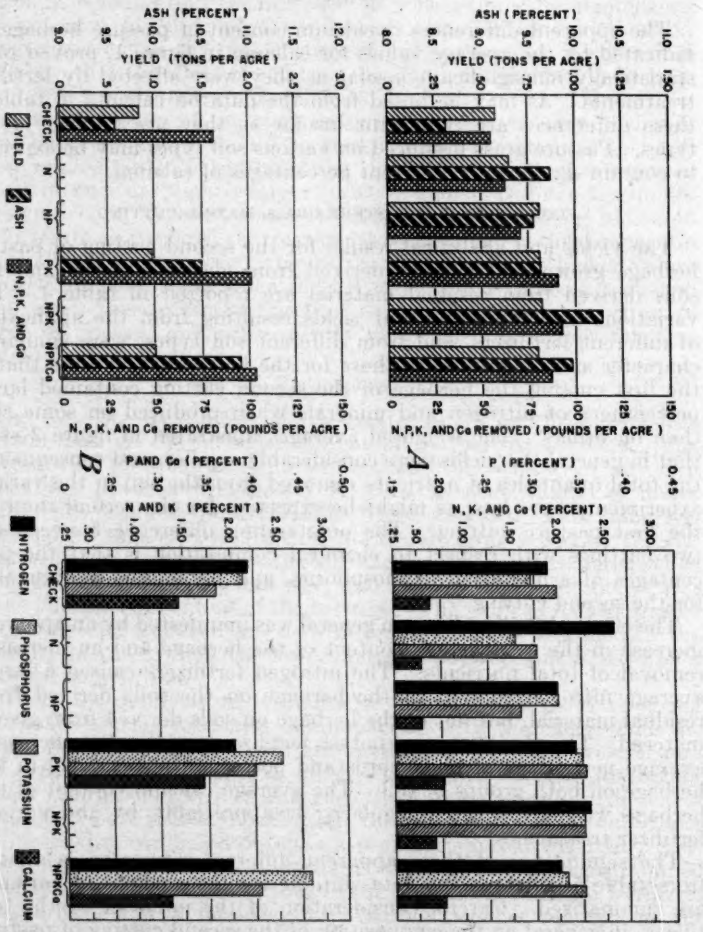

FIGURE 2.—Yield and composition of pasture grass, second cutting, on five soils derived from residual material (*A*) and on five soils derived from glacial material (*B*).

The statistical data pertaining to the effect of soil type on the composition of the second cutting of pasture grass indicate definitely that significant differences in the percentages of nitrogen, phosphorus, potassium, and calcium in the herbage resulted from differences in soil types.

TABLE 4.—*Yield and composition of pasture grass (second cutting) as affected by different fertilizers and different soil types*

SOILS DERIVED FROM GLACIAL MATERIAL

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-29	Custer silt loam	1	Check	1.72	6.42	1.18	.177	0.57	0.47
			N	2.44	4.49	1.10	.114	.37	.37
			NP	2.68	5.35	1.08	.203	.72	.34
			PK	1.35	6.71	1.14	.257	2.13	.52
			NPK	1.67	4.87	1.04	.181	.86	.27
E-37	Bellingham silt loam	1	Check	.53	9.37	2.19	.300	2.52	.43
			N	.51	8.41	1.96	.325	1.74	.40
			NP	.66	9.13	1.76	.315	1.59	.30
			PK	.50	13.53	1.76	.319	1.89	.50
			NPK	1.04	8.69	1.62	.292	1.61	.31
			NPKCa	.98	7.67	1.43	.261	1.40	.35
C-301	Bellingham silt loam	1	Check	.54	9.62	2.74	.489	1.99	.16
			P	.69	10.48	2.46	.498	1.68	.22
			PK	.82	10.01	2.65	.446	3.19	.22
			PKCa	.79	10.00	2.90	472	2.98	.16
			NPKCa	.64	10.80	2.33	.452	3.38	.21
C-305	Puget silty clay	1	Check	1.05	12.29	2.25	.372	2.14	.35
			P	.93	12.20	2.29	.433	2.36	.27
			PK	1.24	11.93	2.51	.479	2.48	.37
			PKCa	1.28	12.89	2.30	.443	2.80	.49
			NPKCa	1.36	13.65	2.17	.443	2.64	.50
C-306	do	1	Check	.91	8.49	2.10	.460	1.38	.26
			P	1.11	9.62	2.07	.574	1.54	.29
			PK	.99	10.28	2.18	.629	1.65	.12
			PKCa	.98	11.13	2.32	.650	1.83	.22
			NPKCa	1.15	11.52	2.06	.680	1.82	.18

SOILS DERIVED FROM RESIDUAL MATERIAL

E-107	Chehalis loam	1	Check	0.99	8.84	1.96	0.287	2.83	0.53
			N	.56	13.00	2.93	.310	2.49	.49
			NP	.95	11.80	2.28	.380	1.82	.47
			PK	.69	10.15	1.88	.370	2.74	.63
			NPK	.93	12.62	3.11	.420	2.67	.77
			NPKCa	.94	11.53	2.68	.373	2.68	1.51
E-55	Sacramento silty clay loam	1	Check	.33	10.83	2.39	.282	.89	1.16
			N	.27	11.12	1.54	.264	.61	.81
			NP	.26	9.82	1.54	.200	.63	.72
			PK	.58	10.58	2.71	.304	1.46	1.39
			NPK	.40	12.90	2.18	.315	1.04	.98
			NPKCa	.23	10.62	1.72	.298	.79	.59
C-302	Chehalis silty clay loam	1	Check	.75	8.70	1.59	.314	1.93	.16
			P	1.09	10.25	1.88	.366	2.55	.18
			PK	.97	10.41	1.54	.373	2.42	.19
			PKCa	1.13	10.33	1.67	.349	2.29	.29
			NPKCa	.95	10.79	1.56	.337	2.66	.24
E-13	Salkum clay loam	1	Check	.87	6.54	1.53	.286	2.05	.68
			N	1.30	5.76	1.81	.242	2.11	.41
			NP	1.44	6.41	2.19	.286	2.58	.66
			PK	.98	6.06	1.47	.238	1.65	.67
			NPK	1.30	6.64	1.65	.265	2.01	.54
			NPKCa	1.34	6.27	1.61	.274	1.84	.60
E-105	Olympic silty clay loam	1	Check	.06	8.28	1.88	.325	2.35	.41
			N	.48	9.06	2.34	.304	1.89	.48
			NP	.61	10.19	2.00	.345	1.41	.36
			PK	.85	10.94	3.36	.465	4.25	.97
			NPK	.67	9.01	2.42	.407	3.39	.46
			NPKCa	.55	10.57	2.59	.387	3.41	1.00

TABLE 5.—*Significance of differences in composition of pasture grass (second cutting) as indicated by analysis of variance (5-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	1.86	1.95	1.81	2.05	2.00	0.78	0.81		
P	.276	.260	0.364*	.326	.313	.064		0.074	
K	1.87	1.54	1.46	2.35	1.93	.99			1.94
Ca	.61	.49	.48	.78	.56	.23			
	Means in percent of dry matter for soils indicated [1]								
	E-107	E-55	E-13	E-105	E-29	E-37			
N	2.43	2.07	1.73	2.40	1.11	1.86	.66		
P	.353	.291	.263	.369	.186	.310	.054		
K	2.51	.93	2.08	2.66	.93	1.87	.84		
Ca	.58	1.01	.50	.54	.39	.39	.20		
N	2.57	1.91	1.80	2.16	1.10	1.88		.66	
P	.364	.298	.269	.386	.205	.307			.051
K	2.78	1.13	1.90	3.33	1.18	2.01			.81

[1] The values for different soils show significant differences among soils.
*=Significant increase.

COMPOSITION OF THIRD PASTURE CUTTINGS AND OF PASTURE HERBAGE FROM ORGANIC SOILS

The prevalence of dry summers in western Washington restricts the growth of pasture herbage during the late summer months on mineral soils with good subsoil drainage because of lack of an adequate supply of soil moisture. In many cases growth was insufficient to justify a third cutting, and consequently only a limited number of third cuttings of pasture were available for analysis.

Two of the pasture experiments were on organic soils both of which yielded three cuttings. Since the parent material and other characteristics of organic soils differ distinctly from those of mineral soils, they were considered separately.

The yields and chemical composition of the third cuttings of the pasture herbage produced on mineral soils and of the three cuttings of the herbage on organic soils are reported in tables 6 and 7 respectively. The yields of the third cutting were small for both the mineral and organic soils. The chemical composition of the third cutting of the herbage varied in about the same order and magnitude as that of the first and second cuttings. No statistical analysis of the analytical data was made because the number of experiments involved was too small.

Organic soils frequently require drainage to lower the water table before they can be used successfully for crop production. A water table sufficiently low to permit normal tillage operations early in the spring, and sufficiently high to provide an adequate supply of moisture by subirrigation during the dry period in summer, is a distinct asset for pastures. Organic soils, therefore, should be especially suitable for pastures if the quality of the herbage they produce compares favorably with that of the herbage produced on mineral soils. Even though only two of the pasture experiments were on organic soils, a general com-

TABLE 6.—*Yield and composition of pasture grass (Third cutting) as affected by different fertilizers and different soil types*

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-105	Olympic silty clay loam	1	Check	0.12	11.63	1.48	0.243	1.69	0.58
			N	.24	8.53	2.96	.333	2.21	.55
			NP	.36	10.34	2.22	.405	2.06	.96
			PK	.91	10.81	3.22	.385	3.31	1.18
			NPK	.42	9.62	2.05	.342	2.04	.50
			NPKCa	.30	11.00	2.48	.355	2.95	1.34
C-305	Puget silty clay	1	Check	.37	11.04	2.45	.342	1.47	.95
			P	.36	10.74	2.79	.422	1.74	.85
			PK	.33	11.70	2.93	.432	1.58	.83
			PKCa	.37	12.01	3.45	.464	2.33	.73
			NPKCa	.42	13.12	3.17	.467	2.21	.78
E-29	Custer silty loam	1	Check	.12	9.38	2.03	.278	1.12	.77
			N	.29	8.46	1.99	.338	1.08	.46
			NP	.21	10.45	2.05	.421	2.43	.85
			PK	.54	9.20	1.92	.304	1.68	.46
			NPK						

TABLE 7.—*Yield and composition of pasture grass on organic soils as affected by different fertilizers*

FIRST CUTTING

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C-303	Peat	1	Check	1.65	5.80	2.02	0.330	0.46	0.42
			P	1.66	5.75	2.10	.449	.28	.58
			PK	1.92	6.73	2.01	.415	1.06	.52
			PKCa	2.04	7.71	1.95	.384	1.44	.56
			NPKCa	2.22	6.73	2.10	.399	.43	.60
C-304	do	1	Check	1.49	5.06	2.47	.255	1.55	.54
			P	1.69	6.67	2.61	.403	1.38	.63
			PK	2.26	6.02	2.26	.325	2.18	.60
			PKCa	2.42	6.28	2.19	.329	2.84	.64
			NPKCa	2.84	6.03	2.34	.302	2.84	.59

SECOND CUTTING

C-303	Peat	1	Check	1.11	9.88	2.58	0.371	1.09	0.48
			P	1.05	8.81	2.48	.494	1.19	.34
			PK	1.30	10.13	2.63	.465	1.71	.27
			PKCa	1.25	11.18	2.38	.432	1.40	.69
			NPKCa	1.47	11.47	2.22	.418	1.10	.63
C-304	do	1	Check	.96	9.07	2.35	.254	.68	.64
			P	.97	8.57	2.80	.396	.55	.49
			PK	1.07	7.83	2.28	.332	1.06	.77
			PKCa	1.06	8.73	2.10	.327	1.61	.84
			NPKCa	1.40	8.91	2.00	.305	1.69	.82

THIRD CUTTING

C-303	Peat	1	Check	0.22	10.02	2.98	0.214	1.22	0.61
			P	.30	8.94	3.18	.243	1.15	.57
			PK	.27	9.11	3.22	.254	1.36	.63
			PKCa	.31	8.96	2.93	.228	1.29	.74
			NPKCa	.54	9.18	2.90	.226	1.10	.70
C-304	do	1	Check	.66	9.41	2.46	.213	4.58	.68
			P	.50	10.27	2.89	.308	5.55	.54
			PK	.82	11.24	2.17	.242	5.25	.64
			PKCa	1.03	9.39	1.93	.227	5.52	.66
			NPKCa	1.15	10.67	1.65	.208	5.05	.82

parison of the chemical composition of herbage produced on organic and mineral soils under similar climatic conditions should be of interest. On the basis of averages portrayed in figure 3 for the first two cuttings, the pasture herbage grown on organic soils had a tendency to be lower in percentage of ash, phosphorus, and potassium than that grown on the mineral soils (figs. 1 and 2), but the yields and nitrogen

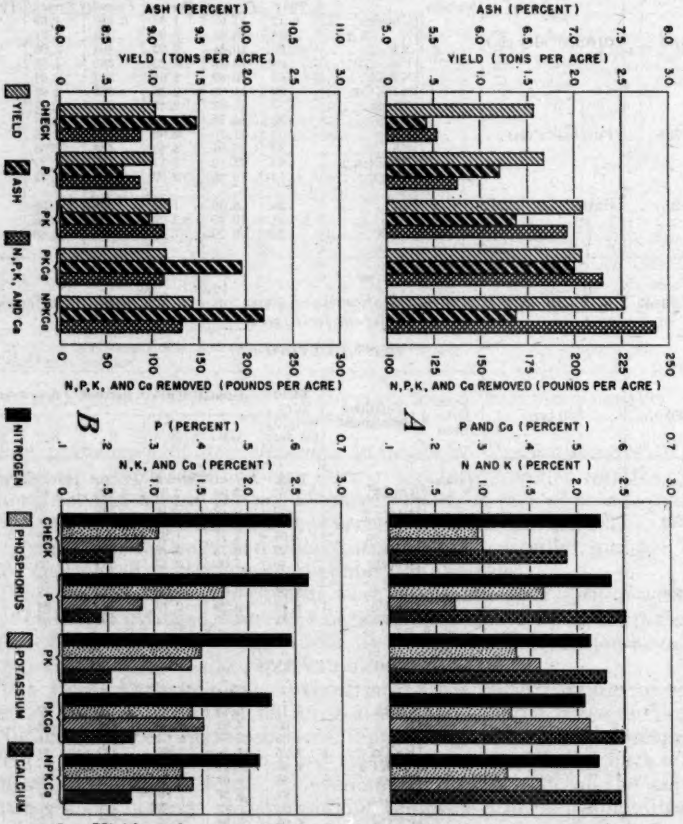

FIGURE 3.—Yield and composition of pasture grass on two organic soils: *A*, First cutting; *B*, second cutting.

content had a tendency to be higher for the herbage on organic soils. The effect of phosphate and potash fertilizers on the organic soils was especially good. It was clearly reflected in the markedly increased percentages of these constituents in the pasture herbage for both the first and second cuttings. With the exception of the P treatment, none of the fertilizers caused larger percentages of nitrogen in the herbage. The data in general indicate that with proper drainage and fertilizing practices many of the peat lands not now utilized for crop production in western Washington could be converted into excellent pastures.

COMPOSITION OF MIXED GRASS HAY

Mixed grass hay consisting largely of various grasses and some clover constitutes one of the principal winter roughages for livestock in western Washington, and therefore the quality of this hay as a livestock feed is important. The samples of hay selected for analysis were obtained from pastures or meadows established for some years, and were composed of different grasses mixed with various amounts of white clover and occasionally some red or alsike clover. The yields and chemical composition of the mixed grass hay samples from 10 experiments on soils derived from glacial material, 2 on organic soils, and 1 on a soil derived from residual material, or a total of 13 experiments, are recorded in table 8. The data show that the yields as well as the composition varied greatly. The extreme values for ash ranged from 4.06 to 10.08 percent, for nitrogen from 0.66 to 2.22 percent, for phosphorus from 0.091 to 0.500 percent, for potassium from 0.12 to 3.82 percent, and for calcium from 0.24 to 1.26 percent. Since the hay samples were cut at the same stage of maturity as nearly as could be determined, it is obvious that the wide differences in composition, and presumably in the quality of the hay as a livestock feed, were affected by the fertilizer treatments, and particularly, by soil properties.

TABLE 8.—*Yield and composition of mixed grass hay as affected by different fertilizers and different soil types*

SOILS DERIVED FROM GLACIAL MATERIAL

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-23	Bellingham silt loam	1	Check	1.54	5.38	1.63	0.273	1.11	0.75
			N	1.03	5.72	2.22	.251	1.28	1.02
			NP	1.57	4.60	1.35	.244	1.05	.36
			PK	2.46	6.01	2.09	.237	1.99	1.07
			NPK	1.69	6.24	2.06	.222	1.60	1.12
E-102	Quillayute loam	3	Check	1.11	4.72	.87	.250	1.89	.28
			N	1.87	4.76	.96	.233	1.67	.27
			NP	2.20	4.47	.98	.235	1.95	.24
			PK	1.92	9.08	2.02	.310	3.82	.88
			NPK	2.89	4.61	1.08	.235	2.28	.25
			NPKCa	3.61	5.12	1.10	.226	2.50	.40
E-1	Everett gravelly silt loam.	1	Check	1.23	4.38	1.01	.164	.68	.43
			N	2.18	5.33	1.48	.164	.95	.66
			NP	3.57	5.04	1.59	.244	1.70	.51
			PK	1.97	7.91	2.11	.274	3.41	.79
			NPK	3.27	6.63	1.52	.240	3.01	.52
			NPKCa	3.47	7.10	1.63	.267	3.08	.75
E-30	Lynden sandy loam.	1	Check	.75	4.67	1.32	.154	.90	.38
			N	1.72	4.06	1.69	.261	.57	.35
			NP	1.26	4.57	1.42	.164	.99	.38
			PK	2.02	5.56	1.86	.236	1.69	.82
			NPK	2.68	5.30	1.72	.219	2.20	.51
			NPKCa	1.99	5.51	1.57	.241	2.16	.61
C-22	Spanaway gravelly sandy loam.	1	Check	1.33					
			N	1.87	7.16	1.20	.158	1.56	1.26
			NP	2.13	5.68	1.03	.177	1.57	.83
			PK	1.06					
			NPK	2.67	5.27	1.04	.156	1.57	.64
			NPKCa	2.80	6.36	.94	.154	2.57	.75
C-301	Bellingham silt loam.	1	Check	1.71	9.55	1.33	.284	.84	.48
			P	2.40	9.22	1.50	.314	.56	.38
			PK	2.26	8.70	1.75	.296	1.01	.60
			PKCa	2.62	9.15	1.53	.290	1.07	.66
			NPKCa	2.55	9.07	1.12	.210	.71	.47

TABLE 8.—*Yield and composition of mixed grass hay as affected by different fertilizers and different soil types*—Continued

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
			Number	*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C-305	Puget silty clay	1	Check	2.65	8.21	1.54	.133	1.42	.96
			P	3.08	8.13	1.37	.221	1.37	.91
			PK	3.07	8.81	1.50	.172	2.23	.76
			PKCa	3.00	9.87	1.48	.244	2.42	1.16
			NPKCa	4.30	8.54	1.36	.174	1.84	.89
C-306	do	1	Check	3.43	6.13	1.34	.410	3.05	.49
			P	3.92	6.36	1.14	.381	2.65	.49
			PK	3.98	5.90	1.33	.313	2.17	.41
			PKCa	4.81	6.63	1.34	.500	3.41	.54
			NPKCa	3.63	8.38	1.39	.468	3.46	.56
E-117	Puget loam	1	Check	4.50	6.62	.91	.159	1.44	.41
			N	4.58	7.40	1.18	.188	1.69	.29
			NP	4.70	6.33	.96	.185	1.18	.27
			PK	3.63	6.97	.66	.166	1.28	.29
			NPK	4.71	7.20	.90	.186	1.12	.30
			NPKCa	5.13	7.81	.89	.197	1.06	.36
E-47	Puget silty loam	1	Check	1.93	8.11	1.65	.234	2.72	.94
			N	2.08	6.84	1.39	.227	2.67	.60
			NP	2.56	8.04	1.80	.282	2.89	.72
			PK	2.14	8.04	1.74	.300	3.12	.68
			NPK	3.32	6.83	1.72	.292	2.48	.42
			NPKCa	3.31	8.72	1.88	.338	3.40	.70
	SOILS DERIVED FROM RESIDUAL MATERIAL								
C-302	Chehalis silty clay loam	1	Check	2.65	8.87	1.30	0.245	1.85	0.25
			P	3.42	8.18	1.54	.286	1.96	.53
			PK	2.58	9.13	1.62	.255	2.21	.95
			PKCa	2.45	8.78	1.24	.257	2.30	.95
			NPKCa	2.54	10.08	.95	.240	2.07	.89
	SOILS DERIVED FROM ORGANIC MATERIAL								
C-303	Peat	1	Check	3.31	7.77	1.41	0.268	1.14	0.55
			P	3.14	6.66	1.42	.358	.83	.73
			PK	3.92	7.25	1.49	.310	1.78	.59
			PKCa	3.84	8.44	1.40	.289	1.83	.64
			NPKCa	4.10	8.50	1.68	.315	1.50	.80
C-304	do	1	Check	2.24	7.66	1.65	.091	.12	.79
			P	2.24	6.99	1.86	.271	.73	.71
			PK	3.38	7.78	1.67	.250	1.49	.61
			PKCa	2.88	6.55	1.52	.224	.82	.60
			NPKCa	3.38	6.96	1.42	.231	.85	.66

On the basis of averages as illustrated in figure 4 for nine soils derived from glacial material and for two organic soils, it appears that applications of suitable fertilizers can be expected to result in increased yields, and consequently in the removal of larger quantities of plant nutrient from the soil.

A comparison of the average values shown in figure 4 with those in figures 1 and 2 reveals that although the yields of dry matter produced by the hay crops were larger than those produced by the totals of the first two cuttings of pasture herbage, the average amounts of nitrogen, phosphorus, potassium, and calcium removed by the hay crops from either the mineral or organic soils, except for the nonfertilized and PK plots on mineral soils, were markedly smaller than the amounts removed by the combined first two cuttings of pasture herbage. Evidently pasture grass draws more heavily on the supply of plant nutrients in the soil than does the mixed hay. Furthermore, it is noted that the average percentages of ash, nitrogen, and phosphorus, al-

though not the average percentages of potassium and calcium, were decidedly smaller in the hay than in the pasture herbage. This explains why smaller quantities of plant nutrients were removed by the hay crops despite their higher yields.

The effect of fertilizers on the composition of hay was less pro-

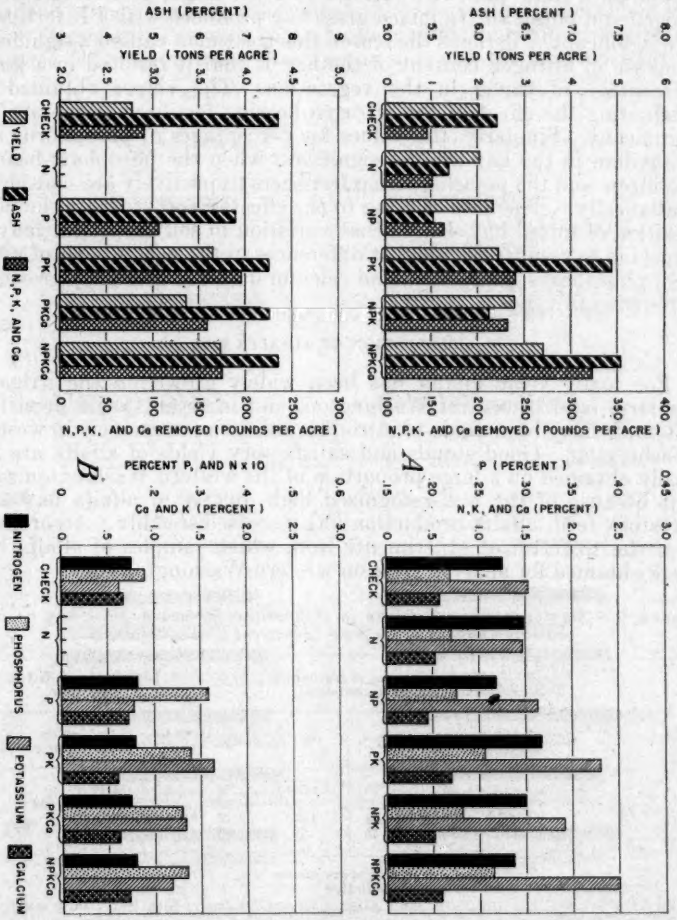

FIGURE 4.—Yield and composition of mixed hay on nine soils derived from glacial material (*A*), and on two organic soils (*B*).

nounced than it was on the composition of pasture herbage. The average values in figure 4 disclose a tendency for the fertilizers to produce a slight increase in the nitrogen content of the hay on the mineral soils, but not on the organic soils. The average percentage of phosphorus in the hay on the mineral soils was not increased appreciably by any of the fertilizers, except the PK and NPKCa treatments, but was

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increased markedly by all the fertilizer treatments on the organic soils.

The significance of the apparent variations in composition of the mixed hay produced on six soils derived from glacial material may be evaluated from the summarized analysis of variance in table 9. These data show that with odds of 19:1 the larger percentages of nitrogen and potassium in mixed grass hay produced with PK fertilizers are significant. Perhaps the reason this treatment caused a significant increase in nitrogen content of the hay is that it resulted in a larger percentage of clover in the vegetation. The values obtained by evaluating the effect of the nitrogen-bearing fertilizers alone are not significant. Similarly, the values for percentages of phosphorus and potassium in the hay are not significant when the phosphate-bearing fertilizers and the potash-bearing fertilizers respectively are considered statistically. The data relating to the effect of soil types on the composition of mixed hay denote that variation in soil properties may be expected to result in significant differences in the percentages of nitrogen, phosphorus, potassium, and calcium in mixed grass hay grown on different soil types.

COMPOSITION OF ALFALFA HAY

For many years alfalfa has been widely grown on the irrigated semiarid land in central Washington, and in recent years persistent attempts have been made to introduce this crop extensively in western Washington. Good stands and satisfactory yields of alfalfa are not easily obtained on a large proportion of the western Washington soils, but because of the well-recognized high quality of alfalfa hay as a livestock feed, alfalfa production has increased steadily. Accordingly 7 of the 13 fertilizer experiments from which samples of alfalfa hay were obtained for analysis were on western Washington soils.

TABLE 9.—*Significance of differences in composition of mixed grass hay as indicated by analysis of variance (5-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	1.23	1.49	1.35	1.75*	1.50	0.49	0.48		
P	.206	.221	.226	.254	.232	.058		0.069	
K	1.46	1.47	1.63	2.55*	2.12	.98			2.30
Ca	.57	.53	.45	.76	.52	.34			
	Means in percent of dry matter for soils indicated [1]								
	E-23	E-102	E-1	E-30	E-117	E-47			
N	1.87	1.18	1.54	1.60	1.92	1.66	.42			
P	.245	.253	.217	.207	.177	.267	.049			
K	1.41	2.32	1.95	1.27	1.34	2.78	.83			
Ca	.86	.38	.58	.57	.31	.67	.28			
N	1.82	.97	1.40	1.54	.99	1.64		.31		
P	.244	.257	.230	.143	.174	.277			.045	
K	1.57	2.66	2.37	1.60	1.28	2.77				.97

[1] The values for different soils show significant differences among soils.
*= Significant increase.

First Cutting

The yields and chemical composition of the first cutting of alfalfa hay for 13 fertilizer experiments are recorded in table 10. The yield data denote that the alfalfa on the majority of the experimental soils responded favorably to fertilizer treatments. It is noted also that the chemical composition of the hay varied widely depending largely upon soil type. The weighted average values for yields and composition illustrated in figure 5 for the western Washington soils and the irrigated central

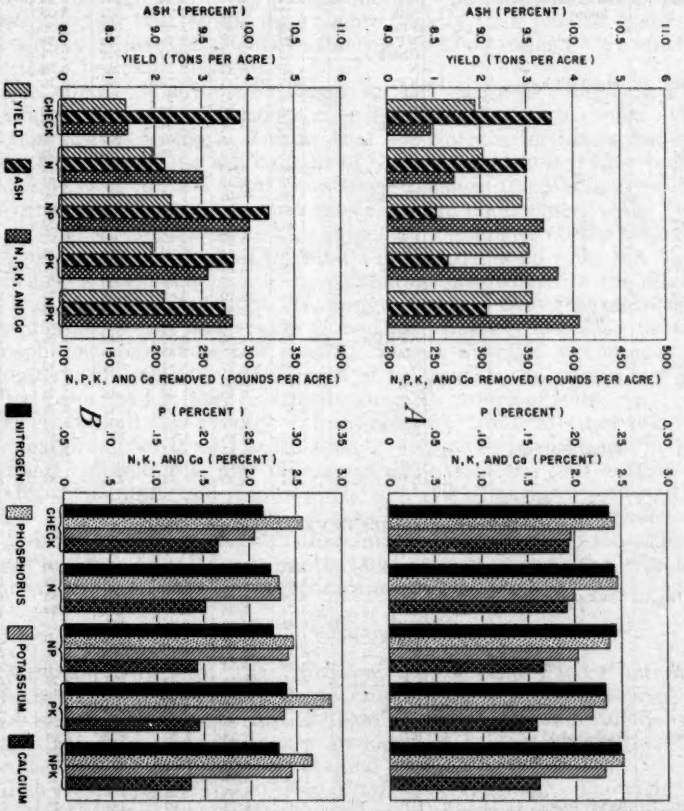

Figure 5.—Yield and composition of alfalfa hay, first cutting, on six arid irrigated soils (*A*) and on seven humid soils derived from glacial material (*B*).

Washington soils respectively indicate some interesting relationships. It may be observed that the average yields of hay and the corresponding quantities of plant nutrients removed from the soil were larger for the alfalfa on the irrigated soils than for that on the western Washington soils. The sum of the quantities of nitrogen, phosphorus, potassium, and calcium absorbed by the first cutting of alfalfa ranged from 170 pounds per acre for the nonfertilized plots on western Washington soils to 408 pounds per acre for the NPK plots on the irrigated soils. When

TABLE 10.—*Yield and composition of alfalfa hay (first cutting) as affected by different fertilizers and different soil types*

HUMID, NONIRRIGATED SOILS IN WESTERN WASHINGTON

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C–50	Dungeness silt loam.	1	Check	2.14	8.68	2.10	0.235	1.96	1.51
			N	2.14	9.78	2.20	.237	3.49	1.20
			NP	3.17	13.66	2.77	.363	3.32	1.58
			PK	3.43	9.40	2.52	.331	2.80	1.45
			NPK	3.22	10.07	2.28	.324	2.88	1.27
E–61	Puget silt loam	1	Check	1.62	8.11	2.22	.296	2.74	1.07
			N	1.76	8.17	2.19	.257	2.54	1.18
			NP	2.19	8.41	2.70	.293	3.10	.96
			PK	2.32	7.71	2.51	.302	2.85	.94
			NPK	2.09	7.69	2.72	.322	2.93	.89
E–56	do	3	Check	1.32	9.14	2.24	.278	1.73	2.03
			N	3.22	8.55	2.54	.274	2.39	1.41
			NP	4.18	8.57	2.36	.259	2.22	1.51
			PK	2.46	9.42	2.62	.328	2.39	1.64
			NPK	2.75	9.11	2.77	.284	2.31	1.54
C–67	do	1	Check	3.07	7.98	1.87	.274	1.99	.90
			N	3.83	8.56	2.15	.317	2.47	1.00
			NP	4.31	8.01	1.63	.263	2.26	.62
			PK	3.72	8.09	1.92	.269	2.07	.59
			NPK	4.51	7.44	2.00	.274	2.14	.81
C–153	Lynden fine sandy loam.	[1] 2	Check	.39	15.27	2.97	.259	.87	2.98
			N	.38	11.57	2.79	.229	.55	3.15
			NP	.44	15.70	2.80	.236	.79	2.81
			PK	.35	15.83	3.27	.314	1.55	2.51
			NPK	.48	16.12	3.01	.288	1.55	2.33
			NPKCa	.45	14.61	3.30	.318	1.55	2.37
C–43	Felida silt loam	1	Check	.43	10.87	1.85	.426	2.41	1.73
			N	.94	8.27	1.84	.314	2.32	1.46
			NP	.81	8.42	1.82	.311	2.68	1.26
			PK	.68	9.19	1.99	.446	2.75	1.48
			NPK	1.45	8.50	1.54	.342	2.58	1.23
C–71	Felida clay loam	1	Check	.68	9.42	1.81	.391	2.73	1.37
			N	1.53	8.88	1.91	.344	2.57	1.21
			NP	1.36	8.85	1.67	.354	2.54	1.25
			PK	.77	9.23	1.87	.367	2.09	1.54
			NPK	.94	9.30	1.74	.378	2.63	1.35

ARID, IRRIGATED SOILS IN CENTRAL WASHINGTON

E–112	Dark sandy loam	1	Check	3.87	7.93	1.86	0.230	2.00	1.14
			N	3.49	7.71	2.03	.213	1.88	1.30
			NP	4.00	8.28	2.19	.229	1.83	1.45
			PK	3.74	7.35	2.01	.241	1.94	1.13
			NPK	3.41	9.79	2.41	.262	2.29	1.61
C–121	Sandy loam	1	Check	1.51	10.27	2.06	.241	2.20	2.44
			N	2.16	10.44	2.15	.258	2.29	2.34
			NP	2.59	10.18	2.35	.231	2.70	2.04
			PK	4.10	11.15	2.43	.237	2.77	2.59
			NPK	3.45	9.34	2.27	.207	2.19	1.99
E–106	Pasco sand	1	Check	1.57	11.15	3.59	.373	2.46	2.42
			N	1.49	10.55	3.34	.323	2.28	2.25
			NP	1.95	9.33	3.30	.332	2.60	1.79
			PK	1.67	9.68	2.83	.270	2.29	1.83
			NPK	2.69	8.91	3.21	.317	2.25	1.62
C–120	Sandy loam	2	Check	1.69	8.89	1.91	.204	1.51	1.96
			N	2.09	8.65	2.26	.257	1.97	1.78
			NP	4.31	6.28	1.96	.188	1.25	1.56
			PK	4.25	7.41	1.83	.214	1.90	1.26
			NPK	4.25	8.59	2.13	.259	2.61	1.42
B–118a	do	1	Check	1.79	8.46	1.81	.198	1.54	1.58
			N	2.38	9.30	2.15	.235	1.76	1.66
			NP	3.41	8.45	2.17	.223	1.68	1.56
			PK	3.15	8.19	2.15	.201	2.05	1.27
			NPK	3.67	7.67	2.20	.231	2.20	1.25
C–101	Winchester sand	1	Check	.98	11.90	2.96	.211	2.03	2.09
			N	.73	10.37	2.65	.189	1.79	2.21
			NP	1.08	8.61	2.64	.217	2.12	1.54
			PK	1.30	8.09	2.68	.232	2.15	1.39
			NPK	1.14	10.07	2.72	.228	2.40	1.75

[1] Poultry droppings 2 years.

this is compared with the values for pasture herbage in figures 1 and 2, it is obvious that the combined yields of the first two cuttings of herbage on the western Washington soils were similar to corresponding yields of the first cutting of alfalfa hay on the western Washington soils, and that the quantities of plant nutrients absorbed from the soil by the two cuttings of pasture herbage were smaller than those absorbed by equal yields of the first cutting of alfalfa hay. In this comparison it is assumed that such atmospheric nitrogen as was utilized by the alfalfa and by the legumes in the pasture herbage passed through the soil. Thus, the fact that alfalfa draws more heavily than pasture grass on the supply of plant nutrients in the soil, and particularly the mineral nutrients, is clearly manifested.

The effect of various fertilizers on the chemical composition of alfalfa hay was not so pronounced as it was for pasture herbage. The average values in figure 5 show that the various fertilizers had an irregular effect on the ash content of the alfalfa, although they had a tendency to produce a lower percentage of ash in the alfalfa grown in the irrigated soils than in that grown on the nonirrigated soils. On an average the fertilizers had no appreciable influence on the nitrogen and phosphorus content of the alfalfa on the irrigated soils, but they did cause a slight increase in the percentage of nitrogen in the alfalfa on the nonirrigated western Washington soils. The PK and NPK treatments on the latter soils caused an apparent increase in the phosphorus content of the alfalfa. Larger average percentages of potassium and smaller percentages of calcium in the alfalfa hay resulted from the fertilizer treatments on both groups of soils.

Even though the average values in figure 5 indicate that some of the fertilizer treatments had a tendency to cause an increase in the nitrogen, phosphorus, and potassium content of the first cutting of alfalfa the summarized results of the analysis of variance reported in table 11 disclose that these apparent increases are not significant. The data in table 11 show further that the apparent reduction indicated in figure 5 for calcium content of this crop on both the irrigated and nonirrigated soils is not significant.

Second and Third Cuttings

Although yields of the third cutting of alfalfa were obtained from several fertilizer experiments, crop samples for chemical analysis were selected from only one of these experiments. The yields and analytical data, therefore, were included in table 12 with those of the second cuttings of alfalfa obtained from 10 experiments.

The yields of the third cutting of alfalfa were small. The yields of the second cutting, as may be noted by examining the data in figures 5 and 6, were less on the average than those of the first cutting. Noteworthy also is the fact that although the fertilizer treatments had an irregular effect on the ash content of the alfalfa, they resulted in the removal of large quantities of plant nutrients from the soil by the alfalfa in all except one case, the PK treatments on western Washington soils, for which the average yield was less than the average yields for the check plots. The quantities of plant nutrients absorbed by the second cutting, while less than those absorbed by the first cutting,

TABLE 11.—*Significance of differences in composition of alfalfa hay (first cutting) as indicated by analysis of variance (5-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	2.25	2.32	2.34	2.36	2.38	0.35	0.44		
P	.278	.265	.269	.289	.286	.058		0.071	
K	2.01	2.18	2.24	2.28	2.38	.53			0.72
Ca	1.79	1.70	1.53	1.51	1.47	.36			
	Means in percent of dry matter for soils indicated [1]								
	Humid, nonirrigated soils								
	C-50	E-61	E-56	C-67	C-153	C-43	C-71		
N	2.37	2.47	2.51	1.91	2.97	1.81	1.80	.17			
P	.298	.294	.285	.279	.265	.368	.367	.028			
K	2.89	2.83	2.21	2.19	1.06	2.55	2.51	.26			
Ca	1.40	1.01	1.63	.78	2.76	1.43	1.34	.18			
N	2.34	2.46	2.48	1.91	2.89	1.76	1.78		.16		
P	.313	.303	.287	.270	.274	.381	.373			.027	
K	2.55	2.84	2.14	2.07	1.32	2.58	2.48				.17
	Arid, irrigated soils								
	E-112	C-121	E-106	C-120	B-118a	C-101			
N	2.10	2.25	3.25	2.02	2.10	2.73	.17				
P	.235	.235	.323	.224	.218	.215	.028				
K	1.99	2.43	2.38	1.85	1.85	2.10	.26				
Ca	1.33	2.28	1.98	1.60	1.46	1.80	.18				
N	2.12	2.21	3.36	2.07	2.08	2.74		.16			
P	.241	.229	.323	.216	.213	.222			.027		
K	2.08	2.39	2.33	2.01	1.93	2.19				.17	

[1] The values for soils show significant differences among soils.

TABLE 12.—*Yield and composition of alfalfa hay (second and third cuttings) as affected by different fertilizers and different soil types*

HUMID, NONIRRIGATED SOILS IN WESTERN WASHINGTON, SECOND CUTTING

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-56	Puget silt loam	3	Check	0.84	8.87	2.29	0.243	1.61	2.36
			N	1.44	7.96	2.52	.259	2.39	1.54
			NP	1.27	7.54	2.34	.254	1.57	1.90
			PK	.76	9.62	2.40	.265	1.57	2.50
			NPK	1.93	7.23	2.57	.282	1.36	1.70
C-67	do	1	Check	1.69	8.41	1.86	.253	1.79	1.39
			N	2.49	8.88	2.74	.263	2.48	1.46
			NP	2.52	8.56	2.19	.240	1.72	1.16
			PK	1.75	8.46	1.96	.222	1.42	1.30
			NPK	2.57	8.10	2.28	.214	1.50	1.36
E-61	do	1	Check	.74	8.20	1.74	.167	2.13	1.43
			N	.56	7.48	1.76	.136	1.94	1.36
			NP	.89	7.58	2.60	.174	1.94	1.25
			PK	.75	8.66	2.22	.166	2.30	1.48
			NPK	1.19	8.29	2.57	.160	2.20	1.53
D-2	Lynden sandy loam	2	Check	.08	9.00	1.79	.390	2.73	1.32
			N	.12	7.48	1.21	.235	2.29	1.28
			NP	.15	7.86	1.31	.244	2.46	1.11
			PK	.18	7.80	2.23	.219	2.71	1.03
			NPK	.18	8.29	1.70	.221	2.37	1.38
			NPKCa	.34	7.30	2.14	.236	2.57	.85

TABLE 12.—*Yield and composition of alfalfa hay (second and third cuttings) as affected by different fertilizers and different soil types*—Continued

ARID, IRRIGATED SOILS IN CENTRAL WASHINGTON, SECOND CUTTING

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
			Number	*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
B-105	Winchester sand	1	Check	3.06	9.24	2.65	.194	2.37	1.57
			N	2.70	8.88	2.68	.203	2.34	1.50
			NP	3.50	8.71	2.78	.238	2.25	1.50
			PK	3.19	7.93	2.87	.240	2.40	1.26
			NPK	3.72	9.29	2.94	.223	2.94	1.43
C-120	Sandy loam	1	Check	1.51	8.05	2.29	.227	1.72	1.67
			N	1.74	9.00	2.66	.275	1.87	1.73
			NP	2.64	7.66	2.77	.267	1.49	1.44
			PK	1.73	8.14	2.79	.293	1.91	1.35
			NPK	2.39	8.38	2.70	.291	2.29	1.39
E-112	Dark sandy loam	1	Check	2.41	9.40	2.20	.205	2.04	1.81
			N	2.41	9.01	2.26	.218	1.88	2.05
			NP	2.85	9.30	2.36	.222	2.06	2.03
			PK	2.68	10.47	2.43	.244	2.23	2.35
			NPK	2.73	10.38	2.48	.241	2.63	1.32
E-106	Pasco sand	1	Check	.93	8.70	2.79	.277	2.43	1.46
			N	1.18	9.17	3.23	.266	2.89	1.32
			NP	1.31	9.10	3.02	.254	2.77	1.49
			PK	1.04	9.33	3.16	.273	2.72	1.68
			NPK	.84	8.01	3.10	.259	2.04	1.59
C-101	Winchester sand	2	Check	1.03	10.67	3.08	.224	2.54	1.79
			N	1.16	9.91	3.15	.218	2.78	1.60
			NP	1.61	10.37	3.61	.300	2.72	1.45
			PK	1.61	9.12	3.08	.247	2.73	1.50
			NPK	1.69	10.57	3.40	.294	3.46	1.42
C-43	Felida silt loam	1	Check	1.44	10.13	2.38	.429	2.79	1.28
			N	1.45	12.75	2.39	.340	2.34	1.43
			NP	2.03	9.70	2.25	.396	2.04	1.42
			PK	1.20	9.67	2.34	.385	2.89	1.36
			NPK	1.86	9.20	2.32	.318	2.45	1.36

HUMID, NONIRRIGATED, SOILS IN WESTERN WASHINGTON, THIRD CUTTING

C-67	Puget silt loam	1	Check	0.51	.....	2.13	0.175	1.66	2.31
			N	.92	.....	2.15	.208	1.78	1.70
			NP	.92	.....	2.22	.189	1.63	2.07
			PK	.78	.....	2.46	.207	1.44	2.36
			NPK	.95	.....	2.15	.164	1.33	1.90

were still large, emphasizing the fact already pointed out that alfalfa in comparison with other forage crops draws heavily on the supply of plant nutrients in the soil.

The response of the second cutting of alfalfa to the fertilizer treatments as manifested by the chemical composition of this crop differed from the response of the first cutting in that, as indicated in figure 6, all the fertilizers caused an increase in the average percentage of nitrogen in the alfalfa on both groups of soils, and a decided increase in the average percentage of phosphorus in the alfalfa grown on the irrigated soils of central Washington. The effect of the fertilizers on the potassium and calcium content of the second cutting of alfalfa was irregular.

The significance of the apparent differences in chemical composition illustrated in figure 6 is expressed in the summarized data for the

analysis of variance in table 13. These data show that the apparent increases in the nitrogen and phosphorus content of the second cutting of alfalfa hay, as indicated by averaging the results, are not significant. Both the data in table 12 and table 13 show that the influence of soil characteristics possessed by different soil types resulted in marked differences in the chemical composition of this crop.

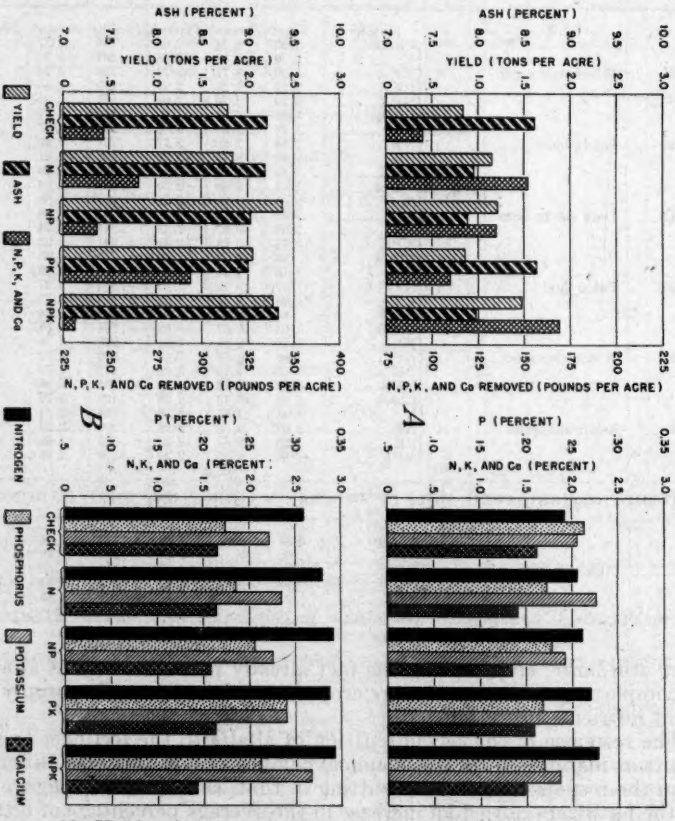

FIGURE 6.—Yield and composition of alfalfa hay, second cutting, from four humid soils derived from glacial material (*A*) and from five arid irrigated soils (*B*).

COMPOSITION OF OATS AND WHEAT CUT FOR HAY

Oats grown alone or as a mixture with vetch are roughages used for livestock in western Washington. Ordinarily the crop is cut in the early dough stage of maturity, and on soils of average fertility it returns better yields of hay than mixed grasses or clover. To a limited extent, wheat cut in the early dough stage is also used for hay in eastern Washington. The yield and composition data for oat hay obtained from six experiments are recorded in table 14, and the

yield and composition data for wheat hay from two experiments are given in table 16.

TABLE 13.—*Significance of differences in composition of alfalfa hay (second cutting) as indicated by analysis of variance (5-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	2.29	2.43	2.52	2.54	2.56	0.39	0.49		
P	.253	.238	.253	.251	.242	.059		0.255	
K	2.16	2.27	2.06	2.21	2.23	.55			0.99
Ca	1.67	1.54	1.53	1.65	1.49	.37			
	Means in percent of dry matter for soils indicated [1]								
	Humid, nonirrigated soils								
	E-56	C-67	E-61	D-2	C-43	C-67a			
N	2.42	2.21	2.18	1.65	2.39	2.22	.21			
P	.261	.238	.161	.262	.374	.187	.031			
K	1.70	1.78	2.10	2.51	2.50	1.57	.29			
Ca	2.00	1.33	1.41	1.22	1.37	2.07	.20			
N	2.43	2.27	2.17	1.50	2.42	2.16		.21		
P	.261	.232	.166	.269	.382	.184			.108	
K	1.51	1.57	2.21	2.60	2.71	1.48				.28
	Arid, irrigated soils								
	B-105	C-120	E-112	E-106	C-101				
N	2.78	2.64	2.35	3.06	3.26	.21			
P	.220	.271	.226	.266	.257	.031			
K	2.46	1.86	2.17	2.57	2.85	.29			
Ca	1.45	1.52	1.91	1.51	1.55	.20			
N	2.76	2.61	2.33	3.04	3.33		.21		
P	.224	.270	.228	.266	.266			.108	
K	2.57	1.97	2.30	2.40	2.91				.28

[1] The values for different soils show significant differences among soils.

OAT HAY

In view of the fact that much of the oat hay produced in western Washington is fed as a substitute for mixed grass hay, an evaluation of the yields and composition of these two forage crops with respect to their relative merits as livestock feeds is a practical consideration. A comparison of the data in tables 8 and 14 and in figures 4 and 7 reveals that in general the yield response of the oat crop to fertilizers and particularly to nitrogen-bearing fertilizers was better than that of mixed grass hay. The oat hay contained a considerably smaller percentage of ash and also smaller percentages of nitrogen, potassium, and calcium (but not phosphorus) than the mixed grass hay. Moreover, despite higher average yields the oat hay removed smaller amounts of plant nutrients from the soil than did the mixed grass hay. In considering the nutritive value of these two forages the relatively low protein and calcium content of oat hay may well be a factor that should serve to detract from its popularity as a winter roughage for livestock.

TABLE 14.—*Yield and composition of oats (cut for hay) as affected by different fertilizers and different soil types derived from residual and glacial material (nonirrigated land)*

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-12	Chehalis clay loam.	1	Check	1.09	5.76	0.96	0.249	0.57	0.24
			N	1.47	5.13	1.31	.173	.41	.22
			NP	2.91	5.47	1.11	.212	1.49	.32
			PK	.79	5.61	.99	.245	.41	.27
			NPK	1.98	5.05	1.00	.233	1.07	.23
			NPKCa	1.38	4.95	.93	.202	.92	.30
E-54	Hesson clay loam	1	Check	1.83	3.94	.81	.172	.63	.17
			N	2.73	3.81	1.14	.153	.83	.22
			NP	3.90	3.78	1.09	.162	.52	.22
			PK	2.16	4.33	.88	.182	.47	.12
			NPK	2.73	4.30	1.15	.184	.93	.23
D-31	Salkum silty clay	2	Check	2.18	4.95	.77	.400	1.19	.19
			N	3.04	6.24	.71	.327	1.39	.21
			NP	3.64	6.28	.94	.367	1.47	.21
			PK	2.91	5.74	.73	.239	1.58	.14
			NPK	3.73	5.59	1.15	.214	1.89	.20
D-12	Olympic clay loam	1	Check	.85	4.20	.70	.251	.59	.28
			N	3.41	4.20	.87	.153	.56	.27
			NP	3.84	3.66	.97	.281	.33	.25
			PK	1.71	4.44	.77	.258	.79	.45
			NPK	3.84	3.57	.77	.204	.67	.32
D-16	Colville silt loam	2	Check	1.95	7.49	1.46	.249	.20	.20
			N	2.37	8.10	1.41	.183	.27	.22
			NP	2.78	8.30	1.14	.254	.13	.25
			PK	2.95	8.21	1.46	.195	.74	.27
			NPK	2.54	7.68	1.30	.179	.38	.17
C-136	Orting loam	1	Check	3.35	5.15	.81	.240	1.45	.13
			N	5.23	5.19	.86	.252	1.66	.14
			NP	6.42	5.48	.82	.247	1.65	.13
			PK	3.20	6.72	.80	.440	1.65	.16
			NPK	7.43	5.15	.86	.243	1.56	.14

Unlike the mixed grass hay whose chemical composition was not affected uniformly or significantly by the application of various fertilizers, the oat hay appeared to be responsive to fertilizer treatments insofar as chemical composition is concerned. A definite increase in the average percentages of nitrogen and calcium, as well as of potassium, in the hay resulted from all the fertilizers applied. The average phosphorus content of the hay, however, was not increased by any of the fertilizers, and seemed to be decreased by the fertilizers which contained nitrogen. While nitrogen applied for this crop caused marked increases in yields, these increases were associated in most cases with reduced concentrations of phosphorus in the plant tissues.

The summarized results of the analysis of variance for the chemical composition of oat hay, recorded in table 15, reveal that although the trends of the average values represented in figure 7 are definitely in favor of higher percentages of nitrogen, potassium, and calcium in oat hay as a result of fertilizer applications, these apparent increases are not significant. When the effect of different soil types on the composition of oat hay is taken into account in evaluating the influence of fertilizer treatments, as shown in table 15, it appears that soil properties had a more potent influence on the composition of oat hay than had the fertilizer treatments.

WHEAT HAY

A careful examination of the yield and chemical composition data in table 16 for wheat hay produced on two central Washington soils under irrigation reveals certain outstanding characteristics when compared with the corresponding average values for oat hay in figure 7.

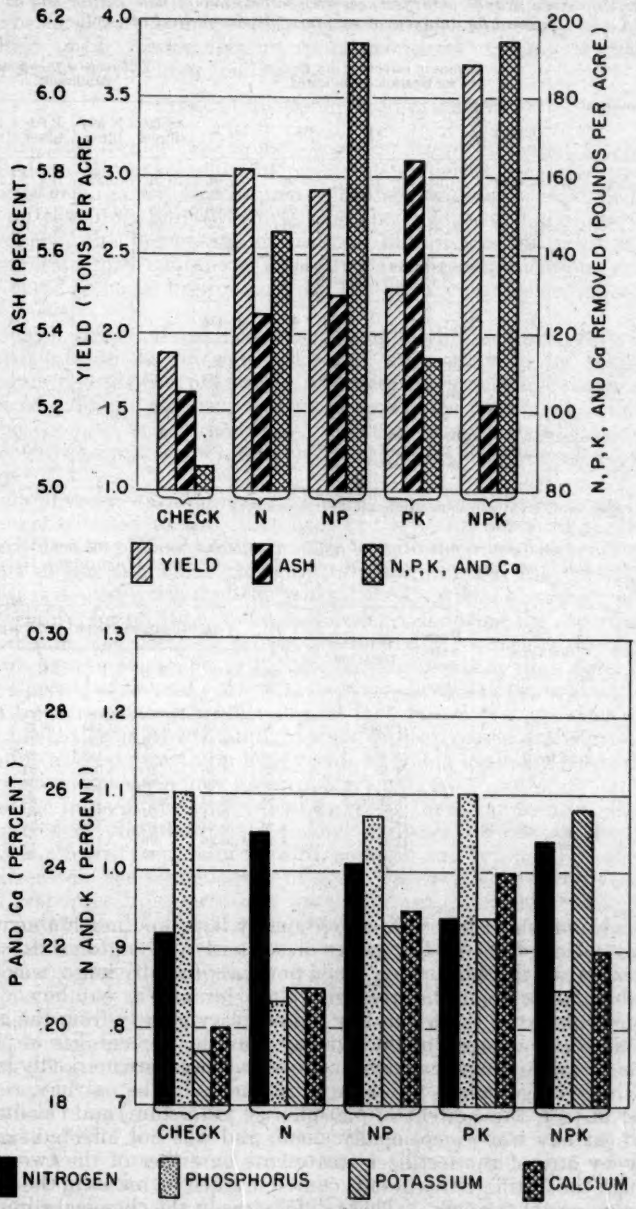

FIGURE 7.—Yield and composition of oat hay grown on six different soils.

TABLE 15.—*Significance of differences in composition of oats cut for hay as indicated by analysis of variance (5-percent level of t value)*

Constituent	Means in percent of dry matter for treatments indicated					Difference required for significance			
	Check	N	NP	PK	NPK	All fertilizers	N fertilizer	P fertilizer	K fertilizer
N	0.92	1.05	1.01	0.94	1.04	0.24	0.32	.....	.....
P	.260	.207	.254	.260	.210	.095	.....	0.132	.....
K	.77	.85	.93	.94	1.08	.46	.....	.....	0.77
Ca	.20	.21	.23	.24	.22	.08	.....	.....	.....
	Means in percent of dry matter for soils indicated [1]								
	E-12	E-54	D-31	D-12	D-16	C-136			
N	1.07	1.01	0.86	0.82	1.35	0.83	.20	.....	.....	.....
P	.222	.171	.309	.229	.212	.284	.073	.....	.....	.....
K	.79	.68	1.50	.59	.34	1.59	.35	.....	.....	.....
Ca	.26	.19	.19	.31	.22	.14	.07	.....	.....	.....
N	1.09	1.05	.89	.85	1.33	.84	.....	.21	.....	.....
P	.235	.175	.305	.248	.219	.292	.....	.....	.087	.....
K	.68	.68	1.55	.68	.44	1.55	.....	.....	.....	.32

[1] The values for different soils show significant differences among soils.

TABLE 16.—*Yield and composition of wheat as affected by different fertilizers and different soil types developed under the arid climate of central Washington (irrigated land).*

Soil No.	Soil type	Years fertilized	Fertilizer treatment	Yield (dry weight) per acre	Constituents in percent of dry weight				
					Ash	N	P	K	Ca
		Number		*Tons*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E-110	Sandy loam	1	Check	5.61	7.98	0.96	0.143	0.27	0.09
			N	6.48	9.47	1.00	.084	.15	.10
			NP	7.96	8.43	1.04	.113	.25	.07
			PK	6.63	8.56	.80	.089	.54	.07
			NPK	7.29	7.57	.99	.132	.34	.09
E-111	Sandy gravelly loam.	1	Check	5.68	10.72	1.02	.156	.49	.13
			N	3.97	9.81	.94	.159	.30	.10
			NP	5.26	10.94	.82	.158	.32	.10
			PK	4.13	10.36	.79	.170	.27	.10
			NPK	4.86	11.45	.89	.154	.36	.09

The yields of wheat hay were exceptionally large and much above the average yields of the oat hay grown on western Washington soils. The ash content of the wheat hay, while not exceptionally large, was considerably larger than the average values for ash in oat hay. The nitrogen content of the wheat hay did not vary greatly from the average values for nitrogen in the oat hay, but the percentages of phosphorus, potassium, and calcium in the wheat hay were markedly lower than the average values for these constituents in the oat hay. As a matter of fact, the content of phosphorus, potassium, and calcium in the wheat hay was exceptionally small, and was not affected significantly by any of the fertilizer treatments on either of the two soils, although the fertilizer treatments caused marked increases in the yields of hay on one of the soils. These differences in the chemical composition of wheat and oat hay while rather outstanding may not be

significant from a practical standpoint, because of the limited number of experiments with wheat hay. Conclusions, therefore, are hardly justified until considerably more experimental evidence is obtained from wheat on different soil types.

CONCLUSIONS AND SUMMARY

When the farmer uses commercial fertilizers, his chief interest is focused on the probability of obtaining sufficient increases in crop yields to secure profitable returns from the extra money expended, and also on the probability of improving the quality of his crops. Any increase in the percentage of protein, phosphorus, or calcium that forage crops may contain as a result of fertilizer applications may be considered to be an improvement in the quality of these crops as livestock feeds.

Four hundred and one forage-crop samples obtained from 45 fertilizer experiments on 29 different soil types were analyzed for their ash, nitrogen, phosphorus, potassium, and calcium content to determine the effect of different fertilizer treatments and soil types on the chemical composition. Certain features which may have significance with respect to the nutritional value of forage crops were revealed by this study.

Undoubtedly variations in meteorological conditions in different years contributed to the differences in the composition of the forage crops. It was not possible to measure the influence of meteorological factors in this particular experimental plan, but had they been measured it is doubtful whether the general results would have been altered appreciably, for no abnormal seasons occurred during the experimental period and the effect of commonly recurring variations in climatic factors have a tendency to be compensating rather than cumulative over a period of several years. Moreover, not all soil types are affected alike by variations in meteorological factors. A wet growing season may benefit crop growth on light soils with excessive drainage and be harmful to crop growth on heavy soils in which drainage is restricted. A dry growing season may have contrary effects.

On the basis of the experimental results there can be no doubt that the nitrogen, phosphorus, potassium, and calcium content of forage crops is affected markedly by differences in soil types. The effect of fertilizers on the composition of these crops is less certain. Since good responses from fertilizers were obtained on certain soil types in each group used for statistical analysis and not on others, it seems that the variability in soil characteristics was too large or the number of soils involved too few to serve as an indication that the changes in composition of the forage crops as affected by fertilizer applications are significant except in a few cases.

Like fertilizers applied to different soils produced markedly different effects on the protein, phosphorus, potassium, and calcium content of forage crops. Certain forage crops were more responsive to fertilizers than others. Pasture herbage proved to be the most responsive, indicating that the effect of fertilizers on the composition of forage crops is more pronounced in the early than in the more advanced stages of growth.

In the majority of cases applications of nitrogen and phosphate fertilizers supplying about 40 to 50 pounds of nitrogen (N) and 80 to

90 pounds of phosphoric acid (P_2O_5) per acre, and complete fertilizer supplying 80 to 100 pounds of potash (K_2O) per acre in addition to the amounts of nitrogen and phosphoric acid mentioned caused marked increases in the protein and phosphorus content of pasture herbage produced on soils in the areas represented by the experiments. With minor exceptions the complete fertilizer under these conditions resulted also in a larger potassium content of the herbage.

The response of mixed grass hay to these fertilizers was similar in character to that of the pasture herbage, but in a less pronounced degree. The general effect of mixtures of phosphate and potash fertilizers was to increase the amount of clover in mixed grass hay and consequently to bring about appreciably larger percentages of protein, phosphorus, and potassium in the hay.

The chemical composition of alfalfa and oats at the hay stage of maturity was less influenced by fertilizer treatments than was the chemical composition of pasture herbage or of mixed grasses in the hay stage of maturity, although the trend of the response of the former crops was in the same direction as that of the latter.

The calcium content of the forage crops was affected markedly by differences in soil types, but did not appear to be influenced to any significant degree by fertilizer treatments, except that applications of complete fertilizers for alfalfa resulted in a reduced calcium content of the hay.

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STUDIES OF MICROBIAL ACTIVITY, CHLORATE REDUCTION, AND CHLORATE TOXICITY IN SOILS TREATED WITH SODIUM CHLORATE [1]

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INTRODUCTION

One of the most important herbicides used in the control of perennial weeds is sodium chlorate. Its efficiency depends largely upon its persistence in the soil in a soluble unchanged condition until it is absorbed by the roots of growing plants. The rate of chlorate application does not foretell the effectiveness of a treatment since decomposition and leaching occur at different rates under different conditions. The factors playing the most important role in causing rapid chlorate reduction are undetermined. Such factors as temperature, moisture, organic matter, nitrates, soil reaction, biological activity, and the chemical and physical changes during the wetting and drying of soils have been reported to influence chlorate reduction or its apparent toxicity (*1*, *2*, *3*, *8*, *10*, *11*, *15*).[3]

That sodium chlorate might affect soil micro-organisms as well as higher plants has also been suggested. Since only a limited amount of work had been reported on this phase of the subject (*1*, *2*, *8*, *12*), the writer, in association with cooperating agencies on weed research at the University of Minnesota, undertook a study of microbial populations and microbial activity in chlorate-treated soils. The studies included (1) effect of chlorate on soil micro-organisms, (2) toxicity of chlorate to plants, (3) influence of plant growth on microbial levels, (4) relation of microbial activity and aeration to chlorate reduction, and (5) effect of fertilizers on chlorate toxicity to plants.

LITERATURE REVIEW

Crafts (*3*) studied several soils under greenhouse conditions and found that increasing the mineral nutrient level of the soil invariably decreased chlorate toxicity.. The addition of nitrates proved especially effective in both soil and nutrient cultures. He reported that chlorate absorption appeared to be a function of root activity and of the concentration and physical and chemical properties of the anions in the culture medium, and that under low nitrate conditions the plant, to its own detriment, will take up chlorate against a concentration gradient.

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[2] The writer expresses appreciation to Dr. H. K. Wilson, of the Division of Agronomy and Plant Genetics, and to Drs. R. B. Harvey and R. H. Landon, of the Division of Agricultural Botany, University of Minnesota, for their counsel and helpful suggestions. Thanks are also extended to Dr. L. M. Stahler, of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, and to Dr. C. E. Skinner, of the Department of Bacteriology and Immunology, University of Minnesota, for their cooperation and assistance in this study.

[3] Italic numbers in parentheses refer to Literature Cited, p. 236.

Rosenfels and Crafts (*14*), studying chlorate toxicity in three different soils, again found that plants grew better on portions of soil in which the nitrates were concentrated. However, they gave no indication of the amount of chlorate reduction that might have occurred at the various nutrient levels during the month the plant seedlings were growing. Undoubtedly they assumed this factor to be negligible, or equal, for all portions regardless of the nutrient level.

Schwendiman (*15*) made studies to determine the relative importance of soil organic matter, soil temperature, and soil moisture as factors affecting chlorate toxicity and decomposition. He found that chlorate decomposition was greatly accelerated by high temperatures in combination with high moisture levels. Furthermore, he found increased catalytic power to be associated with an increase in chlorate decomposition, except under conditions of relatively low moisture and alternate wetting and drying of the soil. In this case the decomposition of chlorate was attributed to chemical and physical factors operating during wetting and drying of the soil. Otherwise the increments in moisture were believed to accelerate the activities of micro-organisms which are then responsible for the greater catalytic activity and the corresponding increase in chlorate decomposition.

Schwendiman attributes the lower toxicity in the presence of organic matter primarily to increments in nitrate content. The only time the rate of decomposition was roughly proportional to the amount of organic matter occurred under conditions of sustained complete soil saturation or when the treated soils were autoclaved.

Åslander (*1*) also mentioned that decomposition of chlorate is probably due to micro-organisms and that it occurs in soils supersaturated with water. He observed species of *Penicillium*, *Aspergillus*, and *Fusarium* together with numerous bacteria growing on top of a hay infusion medium in the presence of tenth normal sodium chlorate. Sodium chlorate did not retard ammonification or nitrification the spring following a fall application. Sodium chlorate is reported as not being detrimental to protozoa or to earthworms.

Bowser and Newton (*2*) found sodium chlorate did not prevent, or greatly affect, nitrification. Nitrification proceeded rapidly in the presence of chlorate when nitrogenous organic matter was added to the soil. In controlled laboratory tests sodium chlorate showed some depressing effect on bacteria and fungi as determined by plate counts.

Wilson, Crim, and Larson (*20*) reported that chlorates were most effective in killing perennial weeds when applications were made during July and August. Hulbert, Remsberg, and Spence (*9*) and Brown [4] found that late-summer and fall applications of chlorate were more effective than spring or midsummer applications and that more chlorate reached the subsoil and persisted for a longer period when applications were made during the fall.

MATERIALS AND METHODS

The studies on microbial activity were begun in the summer of 1940 at the Weed Experiment Station, Lamberton, Minn. At that time no facilities were available for conducting counts of micro-organisms by the dilution method. It was believed, however, that the relative numbers of organisms in soils from various plots might be compared

[4] BROWN, W. J. N. SOME SOIL MOISTURE RELATIONSHIPS IN FIELD BINDWEED (CONVOLVULUS ARVENSIS) CONTROL. Unpublished master's thesis. [Copy on file at the University of Minnesota.] 1942.

on the basis of gas production resulting from their attack on added carbonaceous materials. Dextrose was chosen for the material to be added since it is readily used by a broad group of organisms.

The method employed may be outlined as follows: One hundred grams of soil plus dextrose and water was placed in a 125-cc. Erlenmeyer flask. The flash was then stoppered with a one-hole rubber stopper with an inserted glass tube. Over the outer end of the glass tube was placed a short, flexible, heavy rubber tube and this in turn was closed by means of a screw clamp. The flask was then placed in a constant-temperature water bath. Pressures produced by gases resulting from microbial activity were measured by connecting the flask to a manometer made from capillary glass tubing and releasing the screw clamp. After the measurement the gases were released from the flask and the screw clamp tightened again. Additional readings were similarly taken at stated intervals.

The level of microbial activity in the various soils was determined on the basis of the amount of gas produced, measured by pressure, during the period of incubation. The incubation period and temperature used were approximately 86 hours and 27° C., unless otherwise recorded. The sum of three or more successive readings per sample, taken after 62, 74, and 86 hours of incubation, was used in determining the relative microbial activity of the soils examined.

The soil at Lamberton, Minn., from which samples were taken, has been designated as Clarion silt loam. All samples for comparing microbial activity were taken from the upper 6 inches of soil after the surface debris had been removed. A 3-inch pipe sharpened at one end was driven into the soil to obtain and remove uniform soil cores. Nine such cores were taken at random and then composited for each plot sampled. This composite sample was thoroughly mixed and a portion of it sifted and used. Usually three separate 100-gm. samples were taken from the sifted portion for the determination of microbial activity.

During the winter of 1940–41, controlled experiments were carried out at the University of Minnesota. In these experiments uniform soils obtained from greenhouse storage bins were used. Two series of 100-gm. samples of air-dry soil were placed in glass tumblers and treated with sodium chlorate at two different rates. The soils were incubated at room temperature with the moisture maintained at one-half the water-holding capacity of the soil. Bacterial counts were made according to the technique of Waksman (*18*). Sodium albuminate agar prepared as described by Waksman and Fred (*19*) was used. Ten plates per dilution were poured. Occasionally some plates could not be counted because of the prevalence of molds. In no case were plates counted that had an appreciable growth of mold. The colonies of *Actinomycetes* were included in the counts of bacteria. Two determinations were made of the number of fungi by the plate method; a dextrose-tartrate medium was used.

In the determination of the number of algae Bristol-Roach's method (*18*) was used. Ten replications of each decimal dilution and the tables of probability of Halvorson and Ziegler (*6*, *7*) were employed. Tests for determining significant differences on counts of bacteria and fungi were made according to the *t* test of Fisher (*4*).

The method used for the quantitative chlorate analysis was that developed in the section of agricultural botany, University of Minne-

sota. This method has been used successfully for several years. It does not differ greatly in principle from the method employed by Bowser and Newton (*2*). A summary of the procedure used in making the analyses follows:

Place 100 gm. of air-dry soil in a bottle (300-cc. capacity or more), add 100 cc. of water, and shake (on shaker) for 30 minutes. Then add 10 cc. of 2 percent solution of potassium aluminum sulfate as a precipitant, and centrifuge for 20 minutes. Carefully pipette off a 25-cc. aliquot and put into a 250-cc. Erlenmeyer flask. To this add 25 cc. of 0.1 N (need not be exact but sufficient to reduce chlorate in aliquot) ferrous ammonium sulfate $(Fe(NH_4)_2\ (SO_4)_2.6H_2O)$ and boil gently 5 to 10 minutes. Cool to room temperature and add 10 cc. of Zimmermann-Reinhardt solution (*17, p. 607*). Titrate the remaining ferrous sulfate with potassium permanganate solution of a known normality. Each day boil at least two water blanks (25 cc.) plus 25 cc. of the ferrous ammonium sulfate solution, cool, add Zimmermann-Reinhardt solution, and titrate for checks on the normality of the reducing solution, which may change from day to day. Then obtain the sodium chlorate present in a given sample from the difference in titer.

$$\frac{\text{Ml. for check}-\text{ml. for any sample}}{1{,}000} \times \text{normality of } KMnO_4 = \text{equivalents of } ClO_3.$$

$$\text{Equivalents} - ClO_3 \times \frac{106.45}{6} \times \frac{110}{25} = \text{weight of sodium chlorate per 100 gm. of air-dry soil.}$$

In determining the smaller amounts of chlorate in these experiments, solutions nearer 0.05 N were used. As a preservative, 20 cc. of concentrated chemically pure H_2SO_4 was added per liter of ferrous ammonium sulfate solution. A qualitative test for chlorate, which was found to be helpful in certain cases, was also used. The soil solution was tested on a spot plate by adding one to several drops of a diphenylamine indicator solution which was made of 0.5 gm. diphenylamine, 5.0 cc. concentrated H_2SO_4, and 20 cc. orthophosphoric acid. If chlorate was present, a blue color usually appeared immediately. In concentrated sulphuric acid, nitrates color diphenylamine, though there seems to be a safe distinction between the coloration caused by nitrates and that caused by chlorate even if the concentration of sulfuric acid is raised above the proportions just described. In fact, more sulfuric acid was used in testing certain soil solutions.

EXPERIMENTAL RESULTS

COMPARATIVE LEVELS OF MICROBIAL ACTIVITY IN SOILS FROM FIELD PLOTS TREATED WITH SODIUM CHLORATE

The microbial activity on field plots treated September 15, 1939, with sodium chlorate at the rate of 200, 400, 600, and 800 pounds per acre have been compared. On one series the sodium chlorate was applied in solution, 1 pound of the salt per gallon of water, and on the other series the chlorate was applied in the dry form by means of a dry-chlorate spreader.

There were two series, duplicate plots per series, and two different dates of sampling for each series. The data may be combined inasmuch as the interest is not in the difference between wet and dry applications or between the dates of sampling. The primary purpose of the experiment was to determine the effect of the various rates of sodium chlorate applications on the level of microbial activity in the soil. This is expressed on the basis of the gas produced by the soil micro-organisms (see Materials and Methods) and is recorded in centimeters of mercury. Table 1 gives the results of the various treatments.

TABLE 1.—*Levels of microbial activity in soils treated with sodium chlorate at different rates on Sept. 15, 1939, at Lamberton, Minn., compared in terms of pressures, measured in centimeters of mercury, resulting from microbial activity in closed flasks.*

Treatment rate per acre (pounds)	Date of sampling and plot No.								Mean	Standard error of mean
	Sept. 9, 1940		Sept. 14, 1940		Sept. 19, 1940		Sept. 23, 1940			
	1	2	1	2	3	4	3	4		
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	
200	49.4	43.0	36.9	33.5	48.2	49.2	53.8	45.3	44.9	±1.67
400	29.4	44.1	31.2	38.8	51.6	45.2	54.2	47.2	42.7	±1.67
600	39.6	35.7	24.1	27.4	46.3	42.2	48.6	39.9	38.0	±1.67
800	24.4	31.6	19.8	25.7	45.6	37.4	29.3	33.0	30.8	±1.67

The *F* test of Snedecor (*16*) shows highly significant results for differences in treatments, indicating that the microflora of the soil was affected by the application of sodium chlorate at moderate and heavy rates. The 600- and 800-pound applications gave significantly lower values than the 200-pound application. The data on untreated areas were not included in the analysis of variance since check plots were not available within the blocks. However, by using the results which were obtained on untreated areas for comparison an interesting relationship is evident between microbial activity and the growth of annual weeds. This is shown in table 2.

TABLE 2.—*Levels of microbial activity and amount of vegetation on plots treated with sodium chlorate at different rates* [1]

Date of sampling	Plot No.	Microbial activity in plot series in which $NaClO_3$ was applied dry Sept. 15, 1939, at the rate per acre of—			
		200 pounds	400 pounds	600 pounds	800 pounds
1940		*Percent*	*Percent*	*Percent*	*Percent*
Sept. 9	1	107.0	49.0	76.8	48.1
Sept. 9	2	91.1	94.9	81.7	55.0
Sept. 14	1	95.1	91.4	45.0	41.3
Sept. 14	2	85.8	106.0	73.0	56.7
Average level of microbial activity		94.7	85.3	69.1	50.3
Estimated area covered by vegetation in September		90.0	80.0	60.0	40.0

[1] Values given are in percentages of values obtained for untreated areas (check=100 percent).

In table 2 it may be noticed that microbial activity decreased with a decrease in vegetation, which might have been expected. However, from the foregoing data it is impossible to differentiate between

the effect of the sodium chlorate and that of differences in amount of vegetation.

A similar study was made the following spring on a block of plots on which there was no vegetation. These plots were treated September 15, 1940, and sampled May 8, 1941. Consequently, regrowth of plants had not occurred after the application of sodium chlorate. The lack of vegetation can be explained both on the basis of the higher chlorate content likely to be present in the surface soil and the earliness of the season. In this experiment, duplicate plots were not used. However, plots close together were selected and duplicate samples were taken from each plot. The results are given in table 3.

TABLE 3.—*Comparative microbial activity in soils sampled May 8, 1941, on untreated areas and on areas treated with sodium chlorate at different rates on Sept. 15, 1940, Lamberton, Minn.*[1]

Treatment rate per acre (pounds)	Pressure in sample No.—		Average pressure
	1	2	
	Cm.	*Cm.*	*Cm.*
None	84.5	81.0	82.7
200	89.5	88.0	88.7
600	80.5	73.0	76.7
800	82.5	82.5	82.5

[1] The values are the sum of pressure readings in centimeters of mercury obtained while soils were incubated in closed flasks for 85 hours at 25° to 28° C.

The pressures resulting from microbial activity, given in table 3, suggest that sodium chlorate has little or no effect on microbial activity since the values obtained were high for all treatments. The values reported in table 3 are considerably higher than those in table 1. Numerous factors might have caused this difference, although it is usual for microbial activity to be at a high level during the spring season.

To study the probable effect of sodium chlorate on micro-organisms nearer to the time of application another series of plots was selected. These plots received treatments of sodium chlorate at the rate of 600 pounds per acre on the first of 3 successive months. An adjacent untreated area was studied for comparison with the treated area. A summary of the results obtained for the plots sampled on the various dates appears in table 4.

TABLE 4.—*Levels of microbial activity in soils from plots treated with sodium chlorate and from an immediately adjacent untreated area for various dates of sampling*

Date of sampling	Time of incubation	Temperature	Untreated grain-stubble area[1]	600 pounds $NaClO_3$ per acre applied—		
				Aug. 1, 1941	July 1, 1941	June 1, 1941
1941	*Hours*	*°C.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
Aug. 14	89	28–29	49.1	48.9	42.8	46.7
Aug. 18	89	26–27	40.2	42.1	42.5	.....
Aug. 29	89	32–34	136.9	50.5	.....	.....
Sept. 4	84	29–30	93.7	33.5	.....	.....

[1] Values given are the sums of pressure readings in centimeters of mercury.

In table 4 it is shown that the values obtained for samplings made during the middle of August are comparatively uniform throughout the various treatments. The samples taken August 29 and September 4 on two of the plots show that there was a marked difference between the treated and untreated areas. A comparison of the difference between the area treated August 1 and the untreated area for the two dates of sampling shows that the microbial activity on the untreated area was 270–280 percent above that on the treated area.

The microbial activity increased greatly in the early fall following the removal of the ripened grain crop. This may be explained by the fact that annual weeds became abundant in the untreated grain stubble during the latter part of August. As a result of this growth the surface layers of soil contained many roots, which undoubtedly favored the increase of at least certain species of micro-organisms. The sodium chlorate treatment inhibited the growth of annual weeds on the treated area. The application of chlorate apparently affected the supply of readily decomposable organic matter, which in turn limited the number of active organisms in the treated soil.

CHLORATE REDUCTION

Since the chlorate did not seem to have a direct detrimental effect on microbial activity, studies of chlorate reduction in the presence of a highly active flora were undertaken. The experiments were similar to those just described except that a uniform soil sample was used for each trial and chemical determinations of chlorate were made. There were also certain variations in treatment.

The soil samples for the following experiment were collected in the fall approximately 1 month after sodium chlorate applications on a grain-stubble field. The soils after incubation were left to dry at room temperature for 1 week on tin covers painted with asphalt paint. The treatment and results are given in table 5. A considerable amount of chlorate was reduced since 0.053 gm. of sodium chlorate can be taken as the amount present in all samples at the start. The reduction was not so marked in the samples treated with toluol.

TABLE 5.—*Representative data on 100-gm. portions of a composite sample of soil from a grain-stubble field previously treated with sodium chlorate, showing gas production and chlorate reduction under different conditions.*

Sample No.	Additions to soil	Pressure reading at indicated temperature and hours of incubation [1]—							Total [1]	$KMnO_4$ titration [2]	$NaClO_3$ per 100 gm. of air-dry soil
		32°C., 40.5 hours	32°C., 53 hours	33°C., 65 hours	34°C., 77 hours	32°C., 89 hours	32°C., 113 hours	32°C., 137 hours			
		Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cc.*	*Gm.*
7	2 gm. dextrose +25 cc. H_2O	27	15.2	9.5	5.3	0.7	0.5	0	58.2	11.3	0.027
8	do	34	12.9	12.9	4.4	.7	.8	.2	65.9	12.0	.024
9	do	30	13.9	13.9	4.2	.7	.5	0	63.2	12.5	.031
10	do	34	13.8	8.5	4.7	.8	.5	0	62.3	11.9	.024
11	do	34	12.8	8.2	4.8	.4	1.1	0	61.3	8.9	.037
12	do	35	13.4	8.4	5.1	.8	.8	0	63.5	11.4	.027
19	2 gm. dextrose +25 cc. H_2O +1 cc. toluol	4.3	0	0	.7	−.4	0	0	4.6	8.1	.041
20	do	−.5	0	0	.5	−.5	0	.3	−.2	8.0	.041
21	do	10.3	1.2	0	.8	−.4	0	0	11.9	8.0	.041
29	None—dried immediately									5.3	.053

[1] Values given are in centimeters of mercury.
[2] Titration on water blank = 17.6; titration for soil sample, without chlorate, following incubation = 17.7.

A similar experiment was carried out on a different composite soil sample also taken from a stubble-field plot previously treated with sodium chlorate. In this trial less water was used and two of the samples were left unstoppered. The results, recorded in table 6, again show that a considerable amount of chlorate was reduced during the time of incubation or during the process of air-drying of the samples following incubation. Since 0.037 gm. of sodium chlorate was present at the start of the incubation period, it is apparent that nearly half of the chlorate was reduced.

TABLE 6.—*Reduction of chlorate in soil incubated 169 hours at 28°–30° C., and pressure readings on stoppered flasks*

Sample No.	Additions to soil	Condition of soil in Erlenmeyer flask	Sum of pressure readings	Sodium chlorate per 100 gm. air-dry soil
			Cm.	*Gm.*
21	2 gm. dextrose in 10 cc. water	Packed	46.1	0.020
22	do	do	39.8	.019
27	do	do	(1)	.021
28	do	do	(1)	.021
23	2 gm. dextrose in 20 cc. water	Unpacked	40.0	.021
24	do	do	74.7	.014
25	2 gm. dextrose in 20 cc. H_2O+1 cc. toluol	do	.6	.031
26	do	do	4.4	.031
29	None—dried immediately without incubation			.037

[1] Erlenmeyer flask unstoppered.

Some variation was noted in the pressure readings and in the amount of chlorate reduced. Duplicate samples 23 and 24 were particularly irregular. Sample 24 showed the greatest amount of microbial activity and also the greatest amount of chlorate reduction. Increasing the water increased the average pressure readings, possibly because of the decrease in air volume or an increase in microbial activity resulting from the higher moisture content and better distribution of the dextrose. With relatively small additions of water (10 and 20 cc.), it was observed that the entire mass of soil may not become moistened immediately unless the soil is packed. Since the entire soil sample should be uniformly treated, all likelihood of the added material running down one side of the Erlenmeyer flask and coming in contact with only a portion of the soil should be eliminated. Packing the soil before adding the solution aided in its distribution and increased the uniformity of the results.

Experience has shown that in general heavier applications of sodium chlorate are required for weed control on fertile soils. As a basis for studying chlorate reduction in a very fertile soil a further experiment was undertaken. The soil selected was taken from a plot of land which had been used as a feeding lot for sheep during the fall of the year before sampling. No crop was grown during the following summer and weed growth was kept down by frequent cultivation. Since the soil had not been treated previously with sodium chlorate each individual 100-gm. sample was given 0.04 gm. $NaClO_3$ in solution at the time of beginning incubation. The previous samples tested for chlorate reduction were removed from the Erlenmeyer flasks and left to air-dry at room temperature for a week before the chlorate determinations were made. In this experiment the soils were not dried. The data reported in table 7 show a marked

TABLE 7.—*Gas production and chlorate reduction by a fertile soil supplemented with dextrose, sodium chlorate, and water just prior to incubation in closed vessels at 28–30° C.*

Sample No.	Additions to soil			Hours of incubation [1]												Sum of pressure readings	Titration $KMnO_4$ [2]	$NaClO_3$ remaining	Qualitative test
	Dextrose	$NaClO_3$	Amount total solution	24	36	48	60	72	84	96	108	120	132	144	156	169				
	Gm	*Gm*	*Cc*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cc.*	*Gm.*	
1	2	0.04	10	21.2	28.0	22.9	20.3	17.7	17.2	14.7	8.5	6.4	6.4	5.8	6.5	8.7	184.3	17.9	0	Negative.
2	2	.04	10	21.6	28.2	24.0	23.0	21.8	21.7	20.8	13.6	10.5	9.9	7.6	7.9	10.4	221.0	17.8	0	Do.
3	2	.04	10	21.4	28.2	24.0	23.0	22.5	22.5	20.9	14.3	11.2	10.8	8.5	9.1	11.2	227.6	17.8	0	Do.
4	2	.04	20	35.0	33.0	29.4	27.4	23.4	17.4	10.0	5.1	4.5	6.0	6.5	8.1	9.3	215.1	19.9	0	Do.
5	2	.04	20	35.7	33.0	28.8	26.6	22.5	17.2	10.4	5.3	4.6	6.1	6.2	7.6	8.0	211.3	17.9	0	Do.
6	2	.04	20	11.6	10.5	10.2	20.8	28.7	26.1	19.8	11.5	9.4	9.3	8.2	8.0	9.5	183.6	17.7	0	Do.
7	0	.04	20	−.2	0	.8	.1	.9	.5	1.1	0	0	.8	.7	.6	1.1	6.4	15.2	.011	Positive.
8	0	.04	20	−1.6	0	.8	.2	1.0	.8	1.0	−.2	0	1.0	1.0	.8	1.4	6.2	17.2	.002	Do.

[1] Pressure values given are in centimeters of mercury.
[2] Titration on water blank = 17.7 cc.

acceleration in the rate of gas production and chlorate reduction as compared with the results reported in table 6.

MICROBIAL POPULATIONS IN SODIUM CHLORATE-TREATED SOILS UNDER CONTROLLED CONDITIONS

To determine the microbial populations in sodium chlorate-treated soils under controlled conditions by the dilution and plate-count methods a series of experiments was made.

Waukegan silt loam was used in the first experiment. The soil, after being air dried and sifted, was weighed into 100-gm. portions. Fifteen such samples were placed in glass tumblers and divided into three groups. The first group was left as a control, the second and third were treated with 0.01 and 0.035 gm. of sodium chlorate, respectively. Twenty-one cubic centimeters of water was added to each sample. The amount was determined by taking one-half the water-holding capacity of the soil. At intervals during the incubation period up to 2 months each group was sampled and microbial numbers determined. The results are given in table 8.

TABLE 8.—*Microbial counts at different times on Waukegan silt loam following treatment with sodium chlorate at different rates*

Time incubated	Number of organisms per gram of air-dry soil treated with—					
	No chlorate		0.01 percent of $NaClO_3$		0.035 percent of $NaClO_3$	
	Bacteria	Molds	Bacteria	Molds	Bacteria	Molds
	Millions	*Thousands*	*Millions*	*Thousands*	*Millions*	*Thousands*
2 days	57.5	----------	58.2	----------	50.2	----------
1 week	61.5	----------	82.8	----------	79.1	----------
2 weeks	44.1	----------	43.2	----------	46.0	----------
4 weeks	43.1	68	37.7	62	35.0	63
2 months [1]	26.7	55	40.0*	44	47.9*	48

[1] A determination of algae at this time showed no significant difference between treatments.
*Significantly different from no chlorate.

Since chlorate toxicity is usually considered more pronounced in poor than in fertile soils, a second experiment was conducted in which Anoka loess sand was used. Approximately the same concentrations of sodium chlorate were used expressed in terms of the dry weight of the soil. However, in terms of soil solution this was about double the concentration previously employed since only 10 cc. of water was added, which was one-half the water-holding capacity of the soil. The results are shown in table 9.

TABLE 9.—*Number of bacteria in a sandy soil at different times during a 2-month incubation period following treatment with different quantities of sodium chlorate*

Time incubated	Bacteria per gram of air-dry soil where chlorate added on basis of air-dry soil was—		
	None	0.01 percent	0.04 percent
	Millions	*Millions*	*Millions*
5 days	5.2	5.2	5.2
2 weeks	2.6	2.6	2.9
4 weeks	1.5	2.0*	3.3**
2 months	1.4	1.9*	2.9**

*Significantly different from no chlorate at 5-percent point; **significantly different from no chlorate at 1-percent point.

An examination of the data of table 9 shows that the bacteria survived better in the presence than in the absence of sodium chlorate under controlled conditions even though the chlorate concentration in terms of soil solution was high.

None of the plate counts thus far reported were made on soils in which chlorate had been present for a long time, or on soils to which organic matter was added. In table 9 are given bacterial counts and chlorate determinations for a soil, obtained at Lamberton, Minn., which had remained devoid of plant growth for more than 2 years as a result of treatment with sodium chlorate. The soil was air-dried, weighed into 100-gm. portions, placed in tumblers, treated, and incubated. The samples were air-dried again at the end of the incubation period, and quantitative analyses were made of the chlorate present. Because of previous experience with chlorate reduction in the presence of dextrose, 0.035 gm. of sodium chlorate was added to one group of tumblers along with the dextrose. If chlorate is reduced rapidly in the presence of a very active microflora, some chlorate would be expected to remain at the end of 2 weeks at this higher concentration.

In preparing the experiment it was assumed that the soil was relatively low in microbial activity. Upon adding dextrose an increase in the number of bacteria was anticipated. By adding dextrose it was possible to determine (1) whether bacteria would increase equally well in soils containing low and high concentrations of chlorate and (2) the extent of chlorate reduction at the different levels of microbial activity. The results are presented in table 10.

TABLE 10.—*Bacterial counts and chlorate determinations on soil samples from a field plot, which had remained devoid of vegetation for 2 years as a result of 1 sodium chlorate treatment, the samples having been given different treatments just prior to incubation.*

Incubation time at room temperature	Treatment just prior to incubation					
	None		1 gm. dextrose added per 100 gm. air-dry soil		1 gm. dextrose and 0.035 gm. sodium chlorate added per 100 gm. air-dry soil	
	Bacteria per gm. air-dry soil	$NaClO_3$ per 100 gm. soil	Bacteria per gm. air-dry soil	$NaClO_3$ per 100 gm. soil	Bacteria per gm. air-dry soil	$NaClO_3$ per 100 gm. soil
	Millions	*Gram*	*Millions*	*Gram*	*Millions*	*Gram*
None		0.015		0.015		0.050
3 days	53.2	.015		.014		.048
1 week			641	.013	579	.043
2 weeks	43.2	.015	425	.013	385	.042

The data in table 10 on bacterial counts are not extensive but the values obtained indicate that bacteria multiply in spite of the presence of chlorate. Accordingly, soils not supporting seed-producing plants because of chlorate treatment may be expected to increase in microbial activity when organic matter is added. Only a small part of the chlorate was reduced even though the bacterial activity was high in the samples supplemented with dextrose.

In connection with the experiment reported in table 10 a second group of tumblers was set up in which the fertile soil previously

referred to (p. 228) was used. In this group one-half of the tumblers were treated with 0.04 gm. of sodium chlorate. The results of this experiment are given in table 11.

TABLE 11.—*Bacterial counts on check and chlorate-treated portions of a very fertile soil, and chlorate determinations on treated samples for various periods of incubation*

Time incubated	Treatment		
	No $NaClO_3$	0.04 gm. $NaClO_3$ per 100 gm. air-dry soil	
	Bacteria	Bacteria	$NaClO_3$ remaining
	Millions	*Millions*	*Gram*
3 days	134	139	0.037
2 weeks	340	330	.034
6 weeks	35	32	.026
	32	35	.026

The data of table 11 show that the bacteria were not affected by the addition of sodium chlorate. The rate of chlorate reduction was not excessively rapid, though an appreciable amount of chlorate was reduced in a period of 6 weeks.

The soils treated with sodium chlorate and incubated at room temperature, with a moisture content equivalent to one-half the moisture-holding capacity of the soil, in no case showed a significant decrease in the number of micro-organisms. In certain instances there were significantly more bacteria in the chlorate-treated soils than in the untreated check samples (tables 8, 9). The chlorate was reduced slightly during the time of incubation under the conditions of the experiment. It was believed that a large number of micro-organisms in the soil would greatly hasten the reduction of sodium chlorate, but such was not the case in all instances. The discrepancy can be explained on the basis of the oxygen pressure in the soil. Further studies on the samples of soil analyzed for chlorate reduction and bacterial numbers reported in tables 10 and 11 suggest the factor of aeration.

A quantitative test of the chlorate remaining in the soil after not more than 2 weeks of incubation in tumblers at one-half the water-holding capacity of the soil showed that only a small amount of chlorate had been reduced. After the quantitative chlorate analyses were made the samples were left in the laboratory for 1 week submerged in water. Qualitative tests for chlorate were then made. The tests showed that during the 1 week in which the soils were submerged all the chlorate was reduced in the soils that had a high bacterial count, but not in those that had a low bacterial count. The samples that gave a positive test for chlorate were left submerged for as long as 2 months, but even then all the chlorate was not reduced. The soils showing a high degree of microbial activity evidently became highly reducing when the diffusion of oxygen into the soil became insufficient to supply the biological demand.

CROP YIELDS AND CHLORATE PERSISTENCE ON CHLORATE-TREATED PLOTS FERTILIZED WITH AMMONIUM SULPHATE, SODIUM NITRATE, AND MANURE

When chlorate is to be applied as an herbicide, it is important that enough be used to keep the soil toxic for a sufficient length of time to kill the perennial weeds. Upon eradication of the weeds, however, it is usually desired to resume cropping, and if applications of chlorate have been heavy efficient cropping is often delayed.

Since Crafts (*3*) had found that an increase in the mineral nutrient level of the soil was accompanied by a decrease in chlorate toxicity, a series of experiments was made in which ammonium sulphate, sodium nitrate, and manure were applied to chlorate-treated soil in field plots. The application of the commercial fertilizers was made at such rates that the nitrogen radical would be equal to, or a multiple of, the chlorate radicals applied. The plots were treated in September with sodium chlorate at the rate of 300 and 600 pounds per acre, and the following June ammonium sulphate, sodium nitrate, and manure were applied. The plots were then plowed and seeded to soybeans (*Soja max*). The soybeans, a crop relatively sensitive to chlorate, showed chlorate injury in various degrees throughout the summer. The chlorate injury was reflected in reduced yields of forage (table 12). The lowest yields were obtained from plots in which apparent chlorate injury was most severe.

TABLE 12.—*Sodium chlorate present in the soil and soybean yields (forage), as obtained from samples taken on sodium chlorate-fertilizer plots at the Lamberton Weed Experiment Station, Sept. 26, 1941*

Plot No.	Treatment (per acre)		Soybean yield per acre	Sample depth	$NaClO_3$ in air-dry soil
	$NaClO_3$ applied Sept. 16 1940	Fertilizer applied June 6 1941			
	Pounds		*Tons*	*Inches*	*P. p. m.*
L–1	None	None	2.12		
L–2	600	480 pounds $NaNO_3$	.66	12–24	13
				24–36	39
				36–48	17
L–3	600	374 pounds $(NH_4)_2SO_4$	.67	12–24	4
				24–36	17
				36–48	13
L–4	600	40 tons manure	1.52	12–24	0
				24–36	0
				36–48	4
L–5	None	374 pounds $(NH_4)_2SO_4$	2.16		
L–6	600	None	.56	12–24	0
				24–36	30
				36–48	12
L–22	None	do	1.69		
L–23	300	240 pounds $NaNO_3$	.85	12–24	4
				24–36	21
				36–48	17
L–24	300	187 pounds $(NH_4)_2SO_4$	.76	12–24	4
				24–36	13
				36–48	13
L–25	300	20 tons manure	1.44	12–24	0
				24–36	4
				36–48	13
L–26	None	374 pounds $(NH_4)_2SO_4$	1.96		
L–27	300	None	.97	12–24	4
				24–36	13
				36–48	21
L–28	300	480 pounds $NaNO_3$	.75	12–24	13
				24–36	30
				36–48	21

Contrary to expectation, chlorate injury did not decrease with an increase in the applications of commercial nitrogen fertilizers. Because of the apparent failure of the nitrogen to decrease the chlorate toxicity, samples were taken from the respective plots to determine whether there was any relation between the residual chlorate in the soil and the crop yield. The soil samples taken to a depth of 4 feet showed that the crop yields were lowest where the larger amounts of residual chlorate remained. Apparently chlorate reduction was greatest where manure had been applied. This observation is believed to support the previous evidence of chlorate reduction in the presence of a highly active soil microflora. Although the amount of chlorate remaining in the soil at the time of sampling does not necessarily correlate very closely with yield, it is interesting to note that yield was highest and residual chlorate was lowest on the chlorate treated plots to which manure was applied. No chlorate was found in the surface foot of soil on any of the plots.

The data of table 12, together with the other results, serve to show that the amount of chlorate applied is only one of a number of factors that may influence the quantity of chlorate remaining in the soil.

DISCUSSION

By merely recording the pressures produced over a definite time of incubation the relative microbial activity of soils can be compared. The pressures were considerably reduced by the addition of toluol, thus supporting the view that microbial activity was being measured. The amount of gas produced appeared to correlate well with the numbers of soil micro-organisms and fertility. Good results were obtained when the soils were taken directly from the fields, prepared, and incubated without any loss of time between sampling and the beginning of incubation.

The duration of gas production was relatively short and differed somewhat between soils. It was apparent that the accumulation of staling substances was rapid in all soils, as a foul odor was produced. Gillespie (*5*) reports that accompanying the development of reducing conditions there is the production of a foul odor in most cases, and that some soils become highly reducing when waterlogged.

By analyzing all the data available it appears that organic matter does play a role in the reduction of chlorate as it is a source of energy for the micro-organisms which apparently are an important factor in causing rapid chlorate reduction in soils. During the process of rapid multiplication the increasing numbers and activities of the normal microbes of the soil greatly increase the oxygen demand. Warm temperatures and moist conditions favor microbial growth. On the other hand, increasing the soil moisture decreases the air volume and rate of diffusion into the soil. A consequence of the two actions is an oxygen deficit due to an increased oxygen demand and decreased supply. This results in an accumulation of reducing substances and probably a lowering of the oxidation-reduction potential of the soil. Whether the chlorate reacts with the reducing substances under the conditions of low oxygen pressure, or whether its reduction is the result of a direct biological action, cannot be ascertained from these results. The data do indicate that the normal micro-organisms of the soil are important in creating an oxygen deficit under certain conditions and then directly or indirectly cause a rapid reduction of chlorate.

Whether it be specific organisms or the medium, the influence of the total flora is of primary importance since the flora in general establishes the oxygen demand.

The rate of chlorate reduction seemed to be directly proportional to the rate of formation of reducing substances. The presence of these reducing substances became apparent when the samples were being titrated with permanganate. Several additional cubic centimeters of permanganate solution could be added after the proper end point had been observed and the color would disappear in a short time. The error resulting from reducing substances present in the soil following the clearing of the soil solution as best one could was kept at a minimum by taking the value at which the sample being titrated was first completely colored pink during vigorous shaking. The determination of this point is largely dependent on the clearness of the sample aliquot being titrated.

The addition of Zimmermann-Reinhardt solution was helpful in clearing the sample before titrating with standard potassium permanganate and in increasing the accuracy of the results. When practical a qualitative test was used to confirm the quantitative test. The quantitative method was further checked by comparison with Rosenfels' (*13*) sulfurous acid reduction method.

For rapid chlorate reduction, in addition to high microbial activity there must be incomplete soil aeration, which occurs with heavy precipitation, packing of the soil, and poor drainage. Chlorate was reduced nearly as fast when the soil was packed and the Erlenmeyer flasks left unstoppered as when the flasks were stoppered (table 6).

A year of work in one locality showed that increasing the nitrate content of the soil by applications of commercial fertilizer did not reduce chlorate toxicity under field conditions, while the application of manure resulted in higher yields of soybeans and some reduction of chlorate. Since chlorate has been found to concentrate in plants by movement with the transpiration stream it is not unlikely that under conditions of rapid transpiration the action of nitrates would become subordinate.

In view of the results reported in this paper the rate of chlorate reduction is probably a major factor in determining the efficiency of sodium chlorate as an herbicide. It is likely that persistent plants eventually will be killed by the continued absorption of chlorate even though the rate of absorption is slow. The soybean plants grown on chlorate-treated plots showed more injury from chlorate as the plants developed despite a decrease in the amount of chlorate in the soil with time.

SUMMARY AND CONCLUSIONS

Studies were made of microbial populations and microbial activity in soils treated with sodium chlorate in the amounts usually employed in weed control. Rates of sodium chlorate reduction were observed also. Trials were conducted in the laboratory and in the field. The following conclusions were reached:

(1) Sodium chlorate applied in moderate concentrations does not exert a direct detrimental effect on the soil microflora.

(2) Sodium chlorate applications sterilized the soil for higher plants only and did not interfere with the growth of common soil organisms.

(3) Heterotrophic organisms are limited in their development on treated soil by a decrease in organic matter due to a lack of higher plant growth.

(4) The addition of organic matter to the soil immediately stimulates microbial growth in the presence as well as in the absence of sodium chlorate.

(5) Sodium chlorate is reduced in the presence of active soil microbes. The micro-organisms of the soil are directly or indirectly responsible for the rapid reduction of chlorate.

(6) The rate of chlorate reduction increases with microbial activity under conditions of poor aeration. Packing and moistening of soils which have very active microflora increase the rate of chlorate reduction.

(7) Chlorate is reduced rapidly in a fertile soil when the soil is waterlogged at warm temperatures.

(8) Reducing substances caused by microbial activity under conditions of low oxygen pressure are associated with the disappearance of chlorate in soils.

(9) Aerated soils supplied with readily available organic matter will reduce sodium chlorate in amounts equivalent to 800 pounds per acre when submerged in water, or flooded, for a few days.

(10) Sudden changes in microbial activity and chlorate content of soils are possible. The conditions under which chlorate is applied greatly influence the results.

The reason for the greater success with fall applications of sodium chlorate, and the generally poor results on highly fertile soils under moist warm conditions, can be explained on the basis of these experimental results.

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